Build a Clone of the

Ludwig Phase II Synthesizer

NOTE:
1. If you bought one of the UK Board sets, see Appendix 1 for the errata on this PCB set.
2. 4/30/2012: an error was discovered in the original parts values. The rocker pot is nominally 10K, not 5K as was originally listed. This document has that updated.

This package contains a ready-to-print toner transfer pattern for making a clone of the old and obscure Ludwig Phase II Synthesizer.

“Synthesizer” was a misnomer, as what it really does is to take a normal signal, and create a heavily clipped “fuzz” signal from it, and then run a combination of the dry and fuzz signals through a pair of controlled filters. The filters are set up so they are active at the frequencies of the first two formant resonances of the human vocal tract, producing a very “vocal” and unusual effect. In addition, the fuzz amplitude and movement of the filter resonances may be changed either automatically by an “animation” oscillator or a foot controlled rocker pedal.

This project would never have happened if not for the mania... er, dedication 8-) of Jimi, Dino, and Brian, who collectively made it happen. I wrote down what they dug out and did the PCB for it.

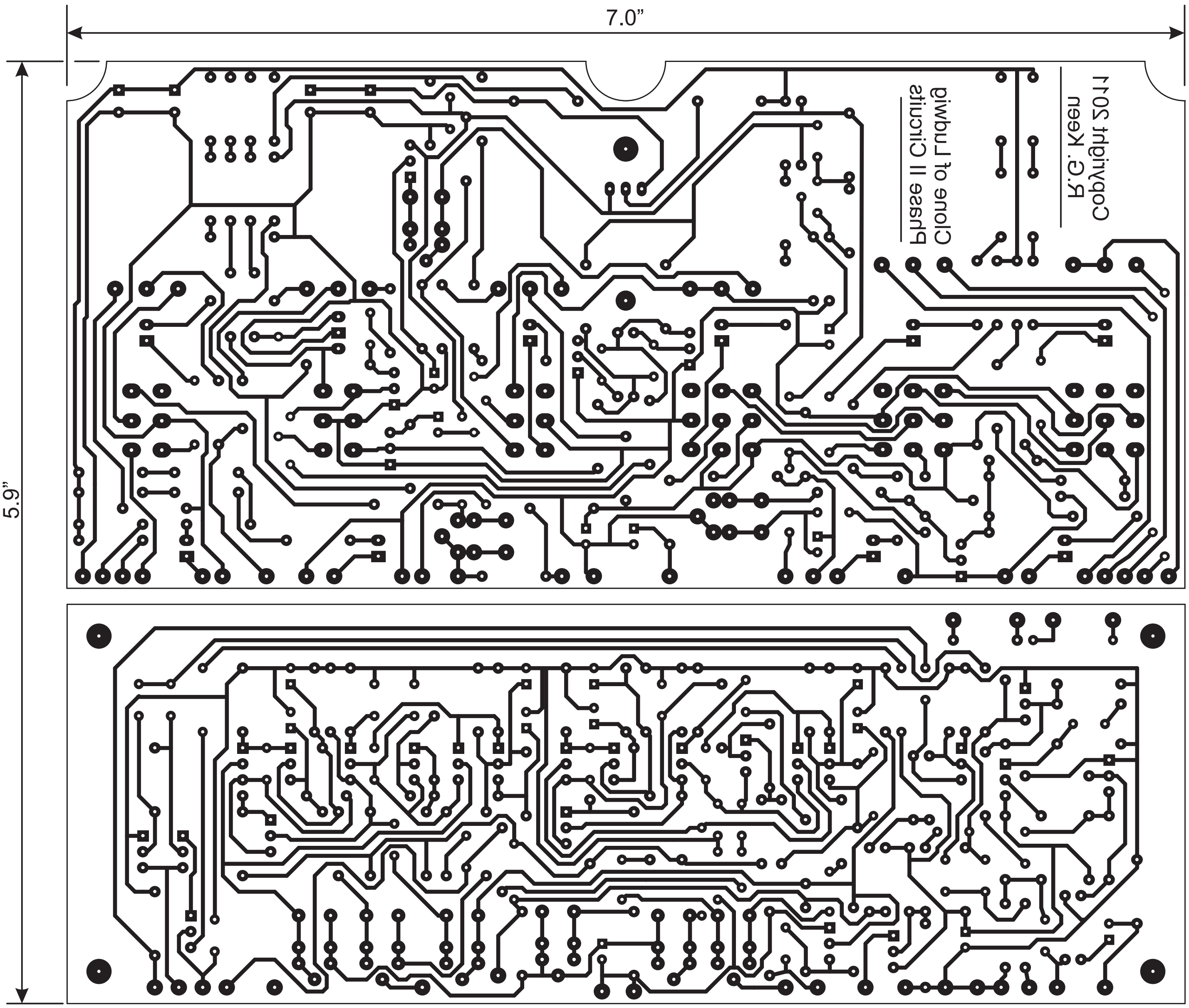
Note that I have made a couple of changes in the circuit that I feel sure the original makers would have done if they could have done. First, I made all the console controls PCB mountable to save some of the vast wiring job that the original needed. Even then, there are nearly three dozen wires to connect the boards with each other and the jacks, stomp switches, etc. second, I modified the switching of the animation panel switch to give the same output waveforms, but match panel switches that are both available and affordable. Finally, I modified the foot-switching setup to use PCB mounted LEDs instead of the incandescent bulbs from the original. I believe that this version will be much more reliable than the originals, because the hardware has fewer off-board interconnections to go wrong, and uses all soldered wires, not PCB slot quick connects.

The complete unit, console/controls board plus filter board, plus footswitching and ancillary wiring can be fitted into a Hammond 1590D sized cast aluminum box, as it was designed for that. Any other metal box with more than 7.1x 4.3x2.0 inch interior dimensions will work as well.

Be sure to read the notes on the box drilling guide on page 5. It makes drilling control locations for the board in a box much easier. Note that the drilling guide only shows you how to drill the critical top of the box. You’ll still need to drill the back for jacks, and that part is not shown, as it is not a critical fit item. You just have to miss the top and bottom PCBs when you do it!

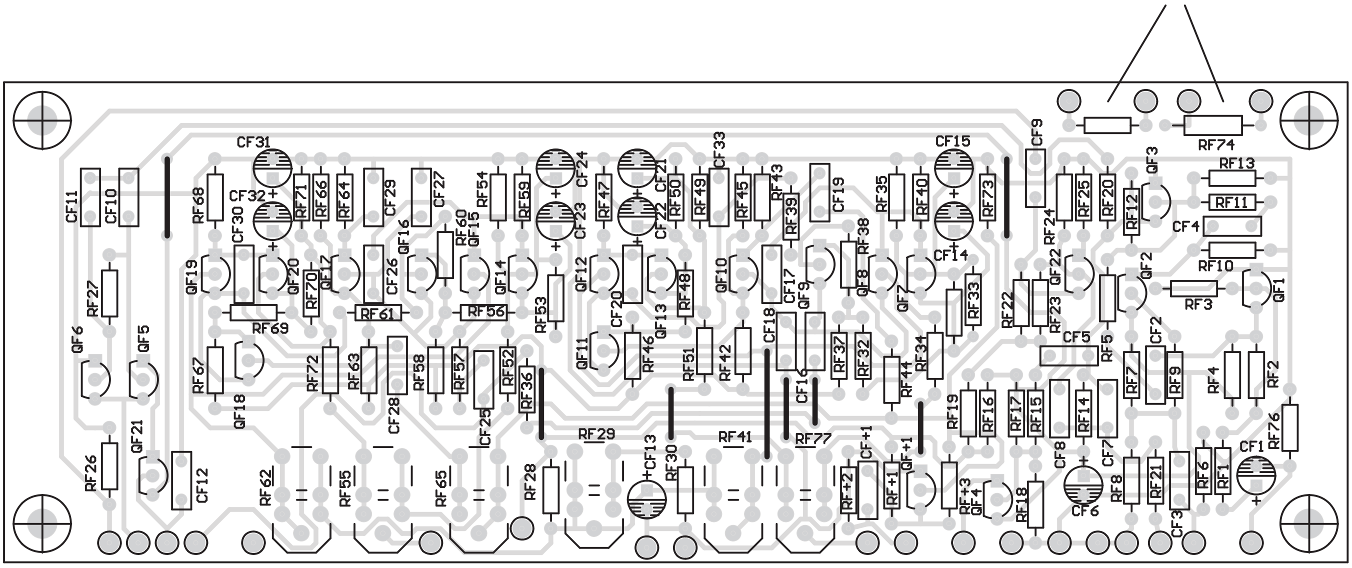
Also note that this project assumes that you have some kind of rocker pedal control to make the unit sweep when it’s in manual mode, not animated. This can be any kind of footpedal rocker setup which holds a 5K linear taper pot driven by the rocker mechanism. This will connect to the main unit through a stereo (tip./ring/sleeve) jack. You could use a manual pot for this, but the most fun will be had when using something like a crybaby footpedal with the stock 100K wah pot replaced with a 5K linear pot. This description does not tell you how to do that, as there may be several ways to get a rocker pedal setup. Imagination and creativity are required for this part of it.

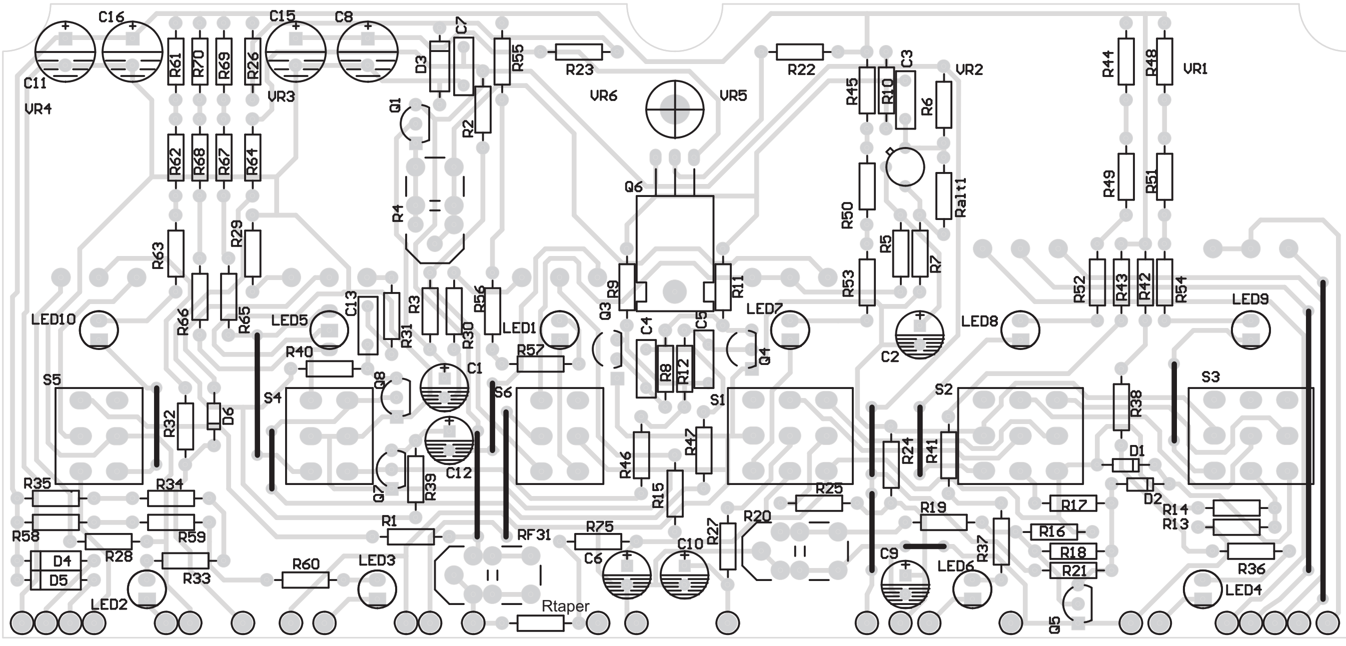
Toner Transfer Pattern



Parts Placement Diagram

Note that RF74 and the un-numbered resistor position next to it are unused in this PCB. Those positions are left there only for compatibility to the original board partitioning. Leave these positions empty unless you completely understand the circuit and are making a physical clone as well as a functional clone of the original.

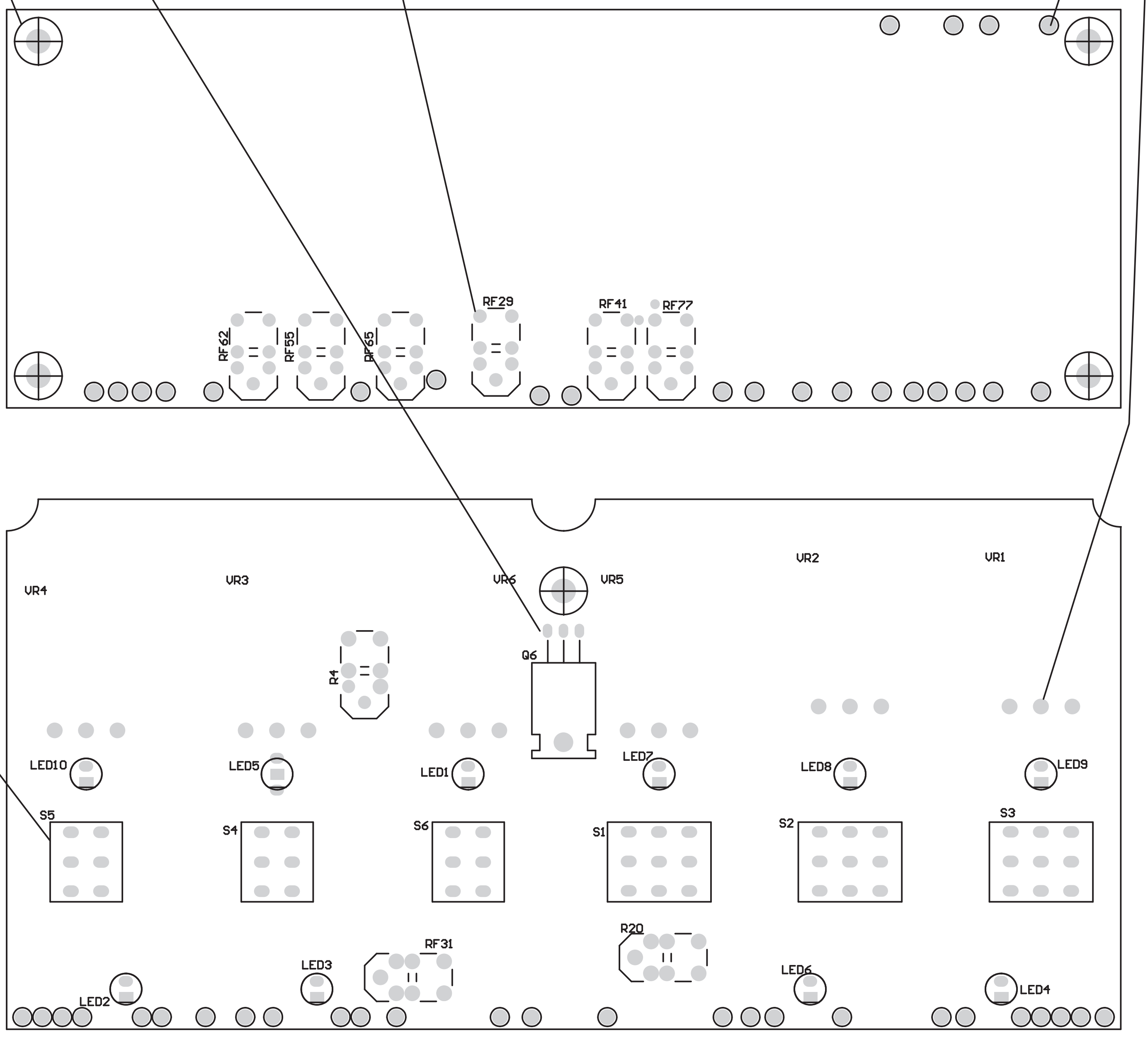




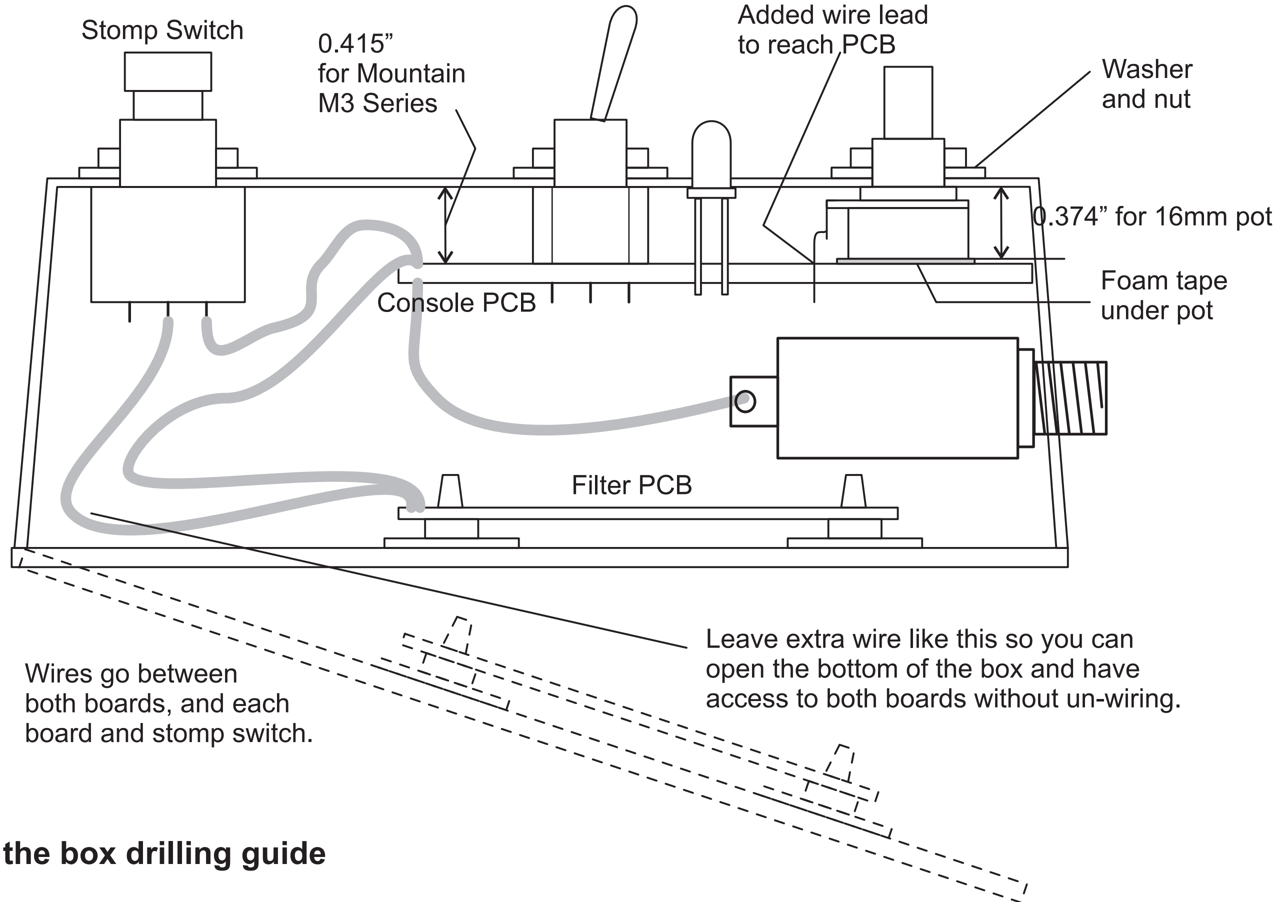
Hole Sizes

If you are making your own boards by toner-transfer or photo techniques, you need to know that the hole sizes are not all the same. All holes about 0.030” except as noted below. Drill all holes 0.030” and then drill out bigger ones to required size. This helps minimize the inaccuracy in locating the holes.

The following holes are likely to need to be larger than 0.030”:
- board mounting holes (5 total); adhesive standoffs need either 0.125” or 0.137” in most cases; if you use screws, size them to match your screws.
- wire pads; I generally use 0.040” to 0.050”; your wires may be bigger or smaller
- LEDs: I generally use 0.035” to 0.040”
- board mounted switches; use the recommended switches, and drill the holes for S1-S6 at 0.073”
- trimmer pots; drill to 0.047” to 0.050” for Bourns types; if using other brands, measure the leads or use the manufacturer’s recommendations
- Q6 legs 0.040”;the hole for Q6 heat tab is optional, but good if you try to put in some small heat sink
- panel pots VR1-VR6; to suit the wires you use in the holes; 0.030” may be fine.



How it fits in the box



Use of the box drilling guide

The box drilling guide on the following page was laid out to make fitting the console board into the box simple(r). Any time you have PCB mounted controls, the PCB sets where the controls go, and the panel has to be drilled to accomodate it.

The drilling guide was laid out with the PCB. Print the box drilling guide. After you drill your PCB and before you put parts on it, put the PCB on a window, lay the box drilling guide on top, and sight through the holes to be sure you have printed it at the right size to fit your PCB.

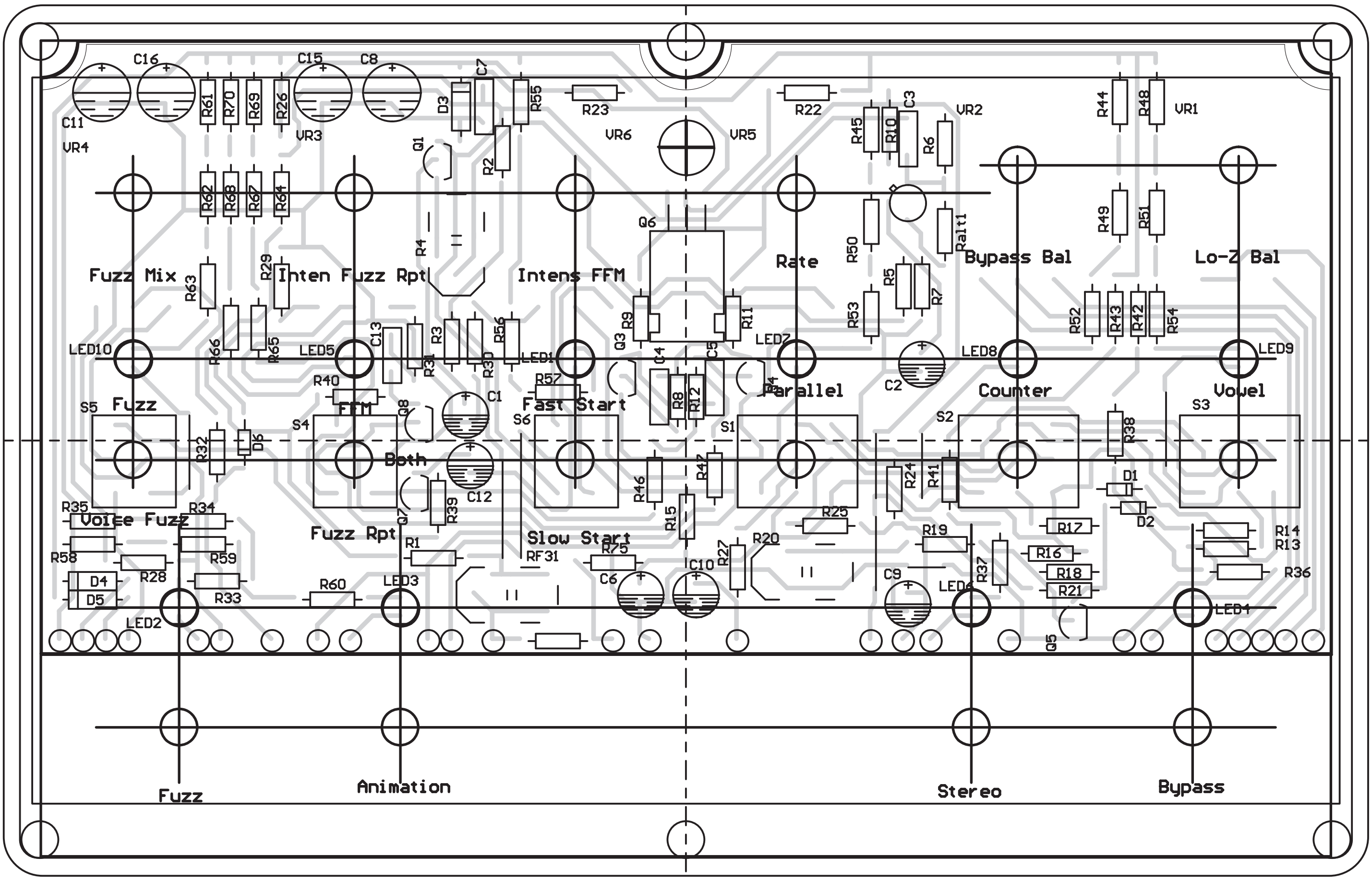
Assuming they fit, mark up/down and right/left center lines on your box. Use a paper punch or knife to cut out the alighning holes in the guide. Place the guide on the box and align the center lines through the aligning holes. When they match, tape the drilling guide in place with masking tape.

Before you mark and drill, think. There is an optional mounting hole on the console board above Q6. This is intended to make the PCB mounting more rigid and less likely to break by using two screws and a PCB standoff there. Unless you have a specific reason to NOT use it, mark and drill it in the box top, and use the standoff.

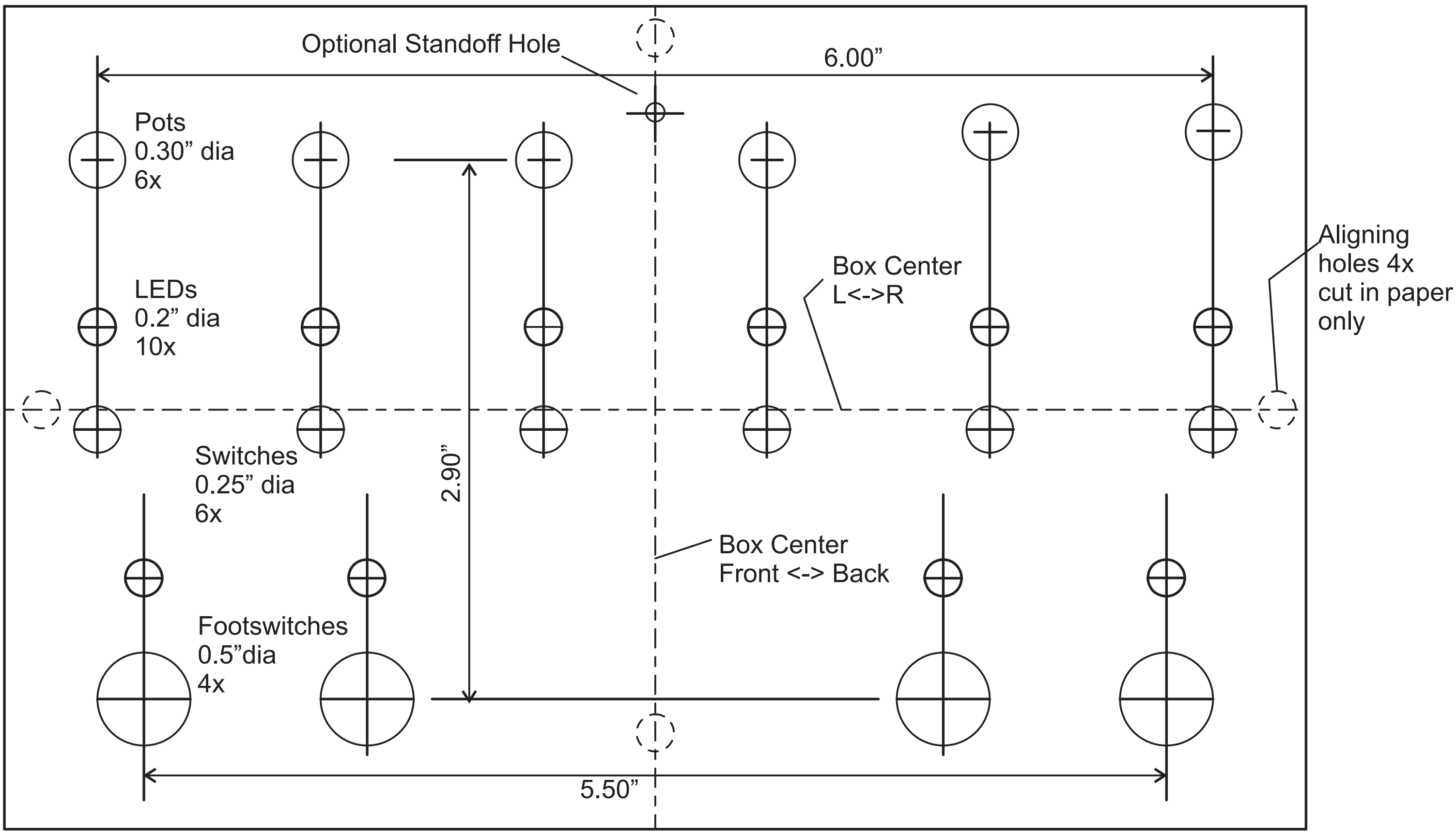
Once it’s in place, use a center punch to mark the box drilling locations. Drill a small hole (0.060-0.085” is a good starting point) at each marked location, and then drill to size with a larger bit. I like step drills a lot for drilling control holes. And they are safer. Remember that drill machines cause more injuries in machine shops than the rest of the machinery combined.

When the board is ready to go it, do any final fitting of the holes with a round (”rat tail”) file.

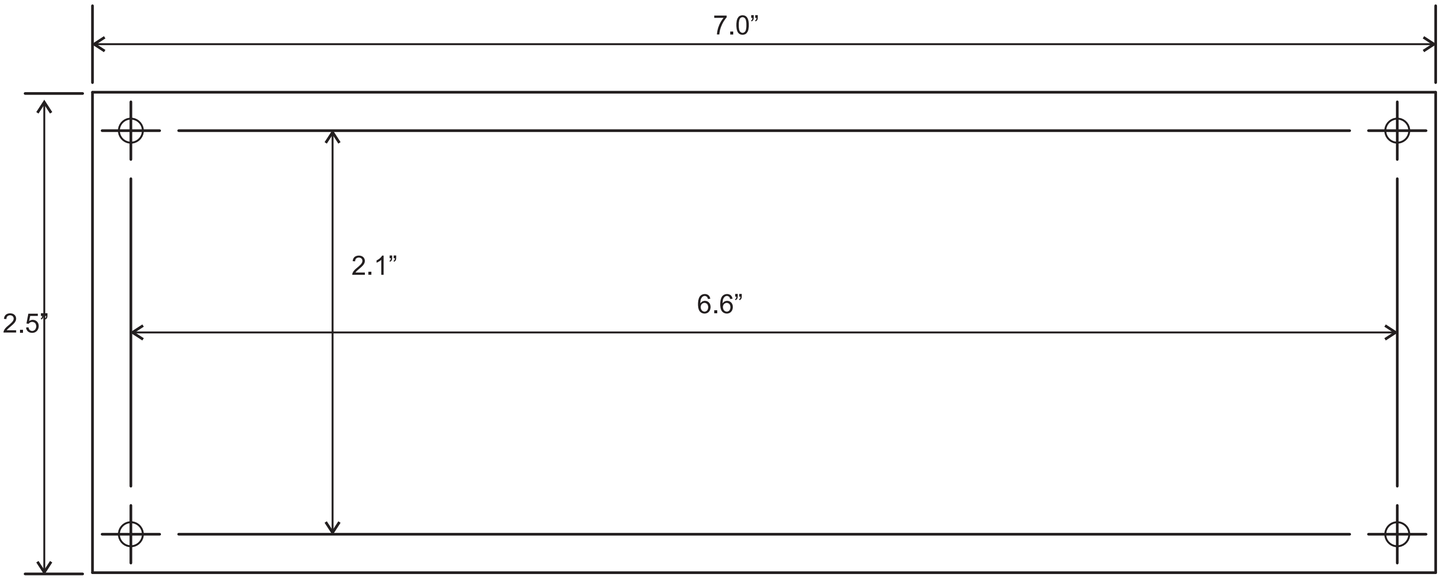
X-Ray View of Controls



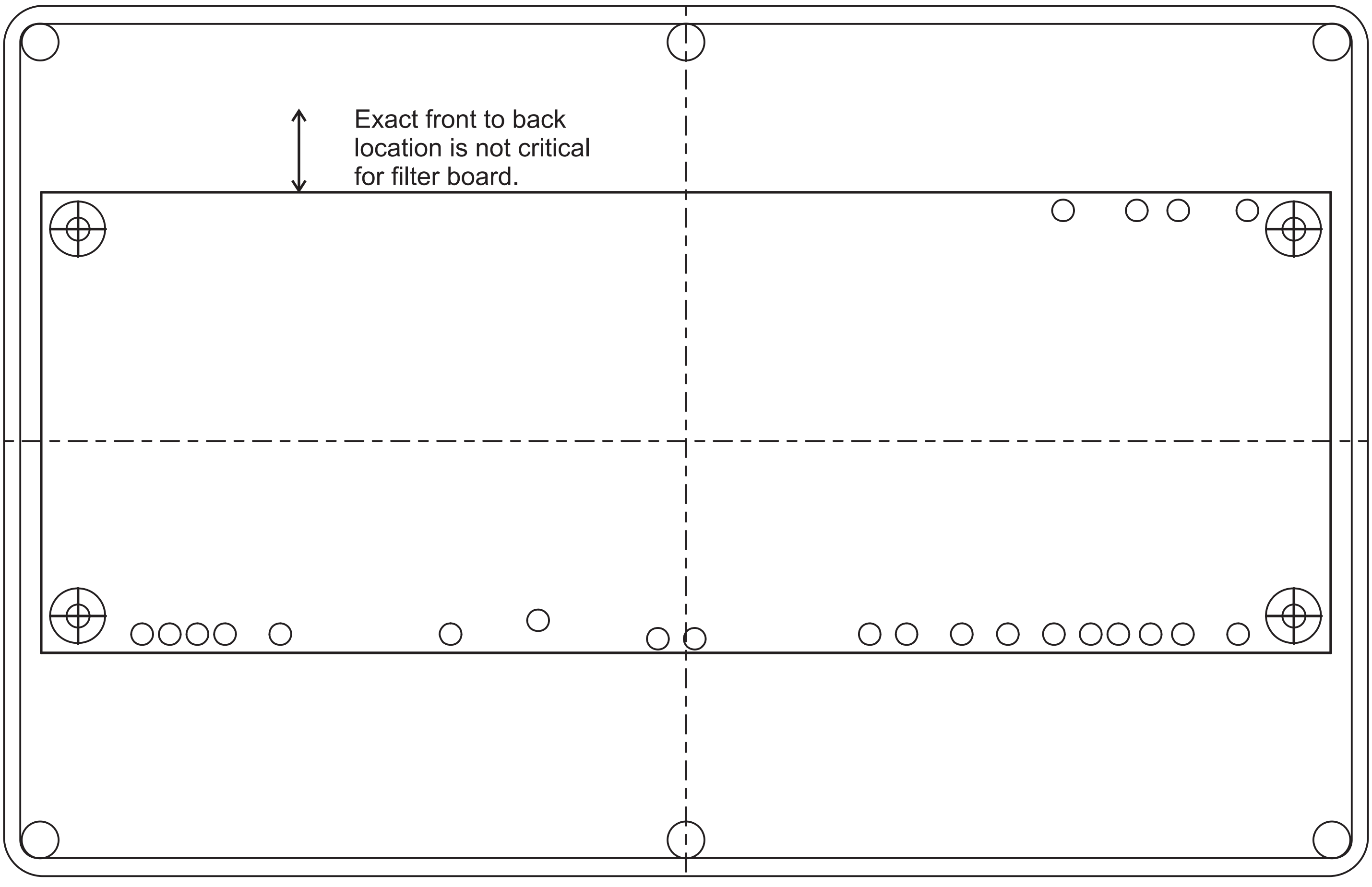
Box Drilling Guide



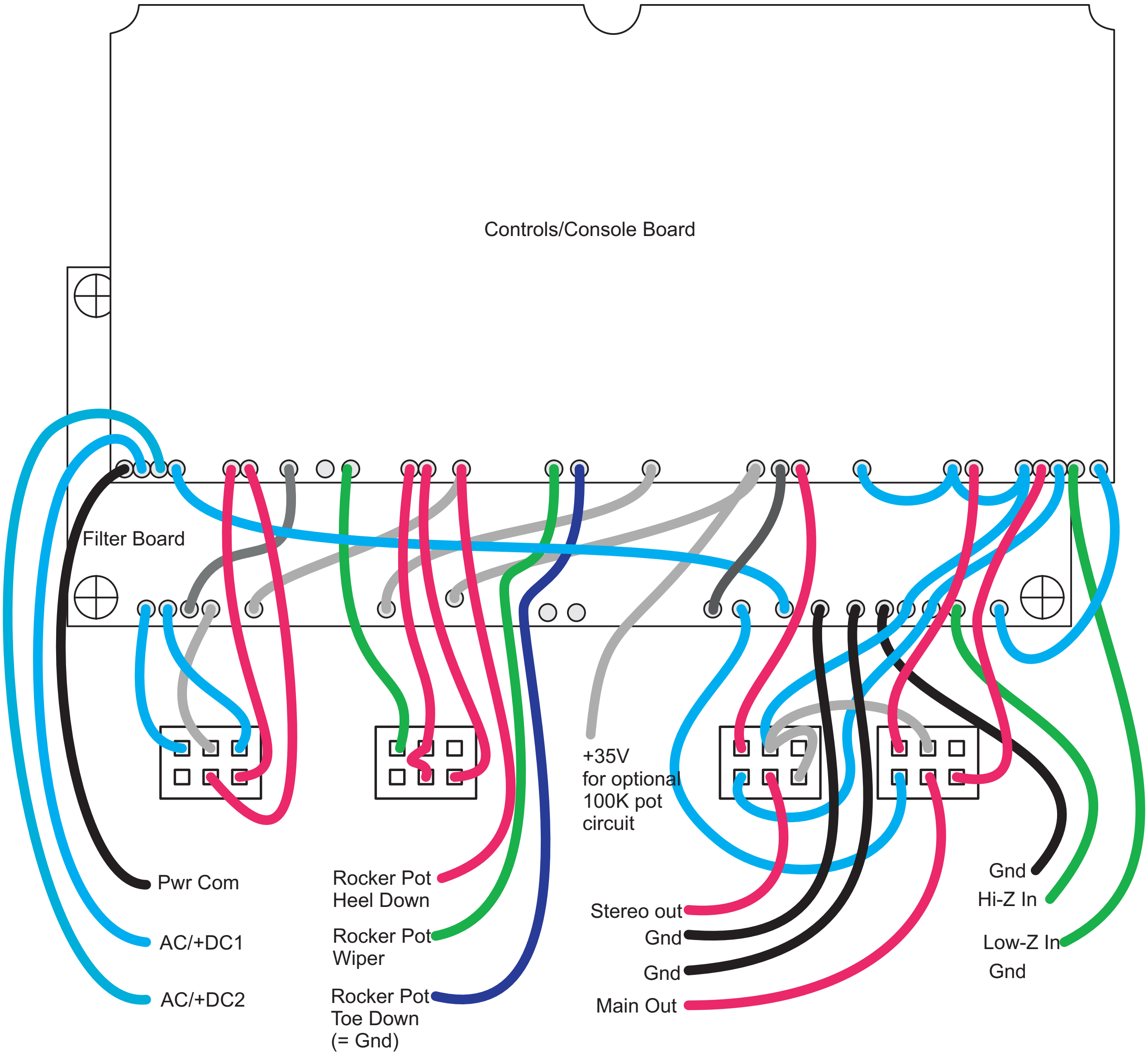
Filter Board Mounting in Box Bottom



Filter board mounting pattern: print on paper and use to locate where the board fits in the box. Note that if you use adhesive standoffs for the filter board, you do not need to drill the bottom of the box for standoffs. I recommend adhesive standoffs.

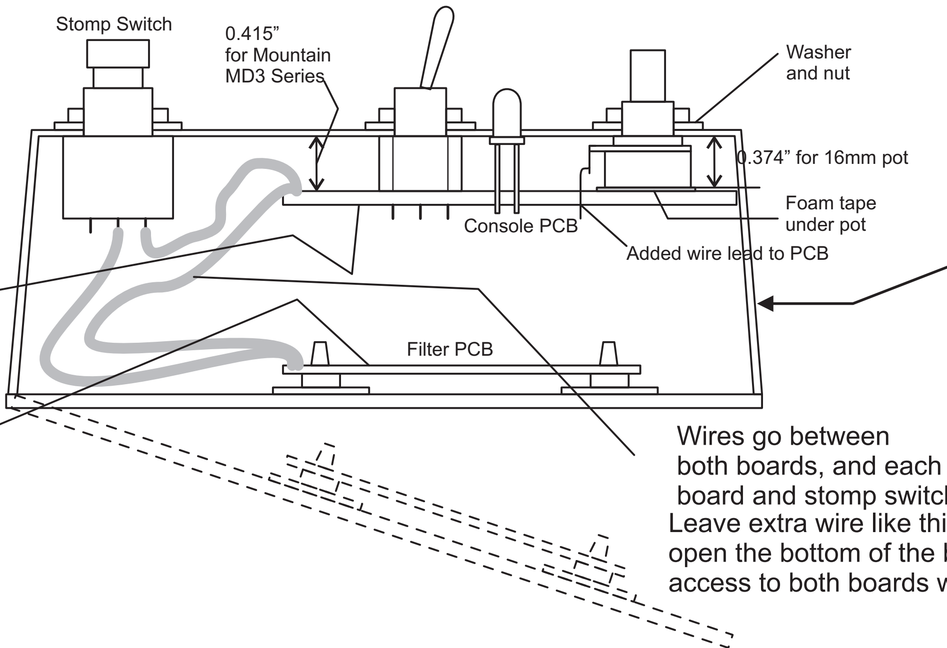


Wiring Guide



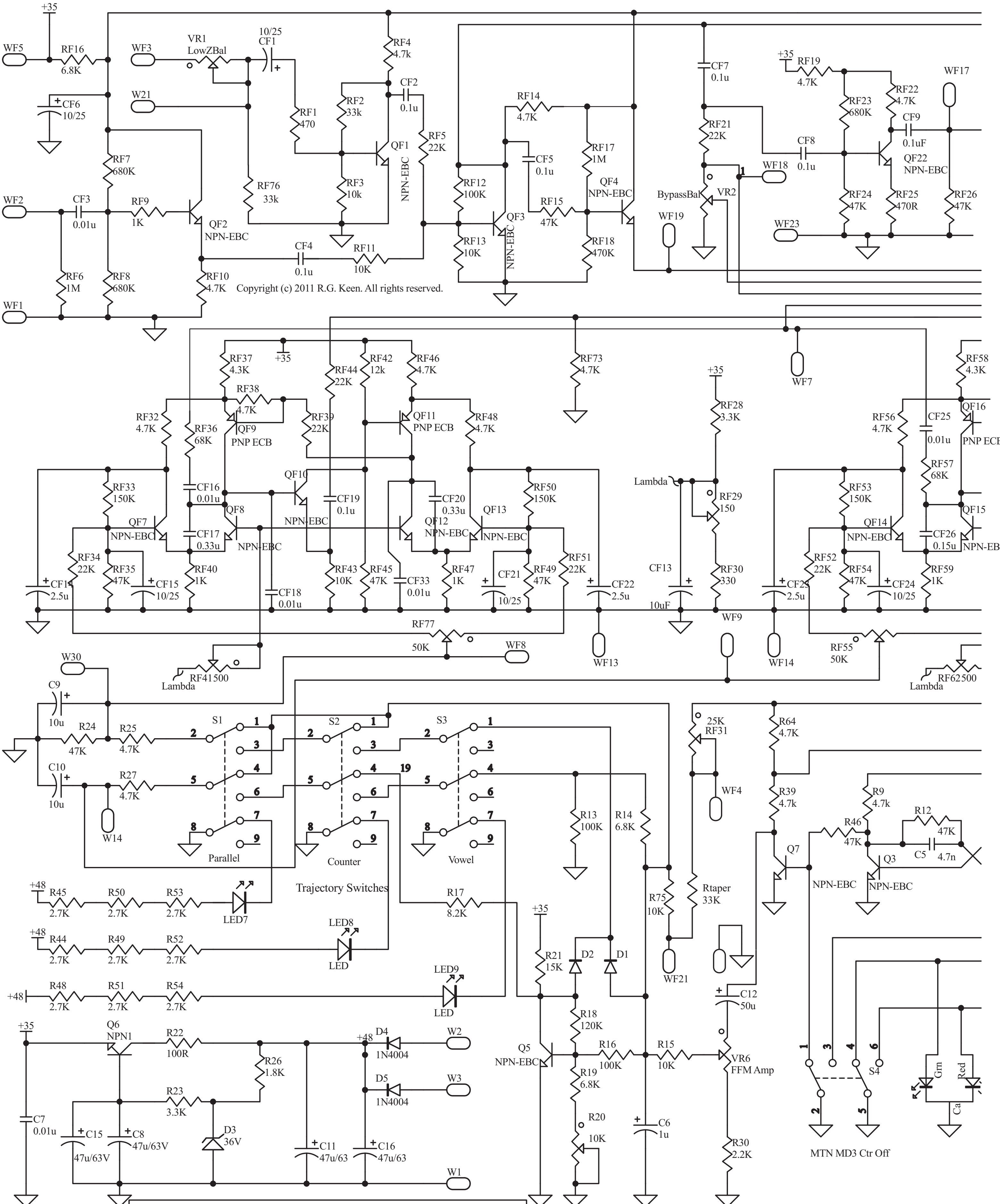
Decide whether you want to adjust trimpots with the console board outside the metal box or inside it. If you want to adjust them with the boards inside the box, solder the trmpots on the bottom of the PCB, not on the top side with the other components.

Trimpots on the filter board should all go on the component side



Jacks go on this surface of the box.Be sure to worry about missing the PCBs!!

Wires go between both boards, and each board and stomp switch.
Leave extra wire like this so you can open the bottom of the box and have access to both boards without un-wiring.



+35
WF5
RF16
6.8K
CF6
10/25
WF3
VR1
LowZBal
10/25
CF1
W21
RF1
470
RF4
4.7k
CF2
0.1u
RF2
33k
QF1
NPN-EBC
RF3
10k
RF5
22K
RF76
33k
RF7
680K
WF2
CF3
0.01u
RF9
1K
QF2
NPN-EBC
CF4
0.1u
RF11
10K
RF6
1M
RF8
680K
RF10
4.7K
WF1
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RF14
4.7K
CF5
0.1u
RF17
1M
QF4
NPN-EBC
RF12
100K
QF3
NPN-EBC
RF15
47K
RF13
10K
RF18
470K
CF7
0.1u
RF21
22K
WF18
BypassBal
VR2
WF19
+35
RF19
4.7K
RF23
680K
RF22
4.7K
WF17
CF9
0.1uF
CF8
0.1u
QF22
NPN-EBC
RF24
47K
RF25
470R
RF26
47K
WF23
RF37
4.3K
+35
RF42
12k
RF46
4.7K
RF44
22K
RF73
4.7K
WF7
RF58
4.3K
RF38
4.7K
RF32
4.7K
RF36
68K
QF9
PNP ECB
RF39
22K
QF11
PNP ECB
RF48
4.7K
+35
RF28
3.3K
RF56
4.7K
CF25
0.01u
QF16
PNP ECB
RF57
68K
RF33
150K
CF16
0.01u
QF10
CF19
0.1u
CF20
0.33u
RF50
150K
Lambda
RF29
150
RF53
150K
QF7
NPN-EBC
QF8
NPN-EBC
QF12
NPN-EBC
QF13
NPN-EBC
QF14
NPN-EBC
QF15
NPN-EBC
CF17
0.33u
CF26
0.15u
RF34
22K
RF35
47K
RF40
1K
RF43
10K
RF45
47K
CF33
0.01u
RF47
1K
CF21
10/25
RF49
47K
RF51
22K
CF13
RF30
330
RF52
22K
RF54
47K
RF59
1K
CF14
2.5u
CF15
10/25
CF18
0.01u
CF22
2.5u
10uF
WF9
CF23
2.5u
CF24
10/25
RF77
50K
WF8
WF13
WF14
RF55
50K
Lambda
RF41500
Lambda
RF62500
W30
C9
10u
R24
47K
R25
4.7K
S1
S2
S3
C10
10u
R27
4.7K
W14
Parallel
Counter
Vowel
Trajectory Switches
19
25K
RF31
WF4
R64
4.7K
R39
4.7K
R13
100K
R14
6.8K
R9
4.7k
R12
47K
R46
47K
C5
4.7n
Q7
NPN-EBC
Q3
NPN-EBC
+48
R45
2.7K
R50
2.7K
R53
2.7K
LED7
R75
10K
Rtaper
33K
R17
8.2K
+48
R44
2.7K
R49
2.7K
R52
2.7K
LED8
LED
+35
R21
15K
D2
D1
WF21
+48
R48
2.7K
R51
2.7K
R54
2.7K
LED9
LED
C12
50u
+35
Q6
NPN1
R22
100R
+48
D4
1N4004
W2
R18
120K
Q5
NPN-EBC
R16
100K
R15
10K
VR6
FFM Amp
S4
Grn
Red
R26
1.8K
D5
1N4004
W3
R19
6.8K
R23
3.3K
Ca
D3
36V
R20
10K
C6
1u
R30
2.2K
MTN MD3 Ctr Off
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C15
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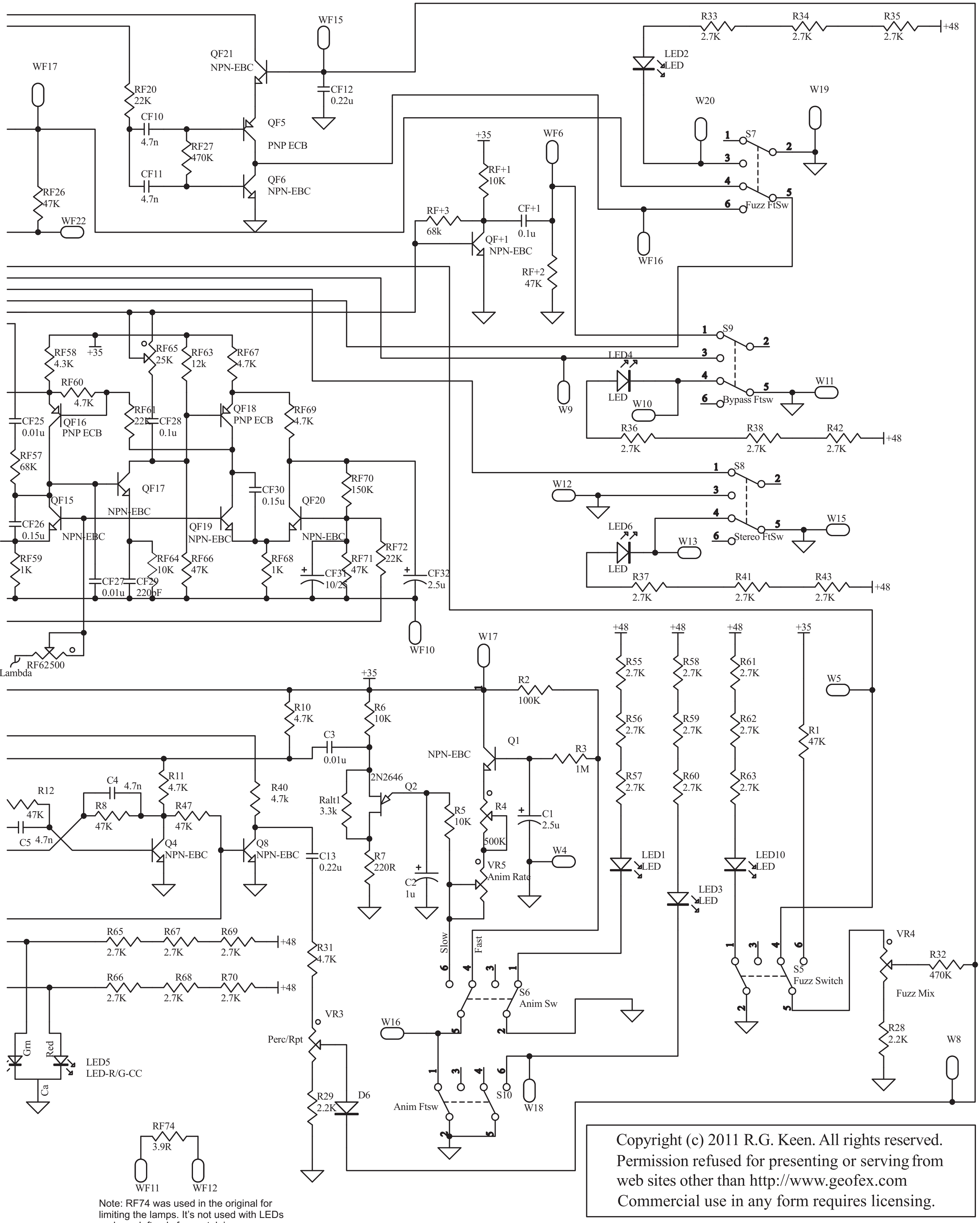
C8
47u/63V
C11
47u/63
C16
47u/63
W1



Note: RF74 was used in the original for limiting the lamps. It's not used with LEDs and was left only for nostalgic purposes.

Circuit Modifications from the Original

The Phase II was a remarkable setup for its time. Like many big technology steps, however, it suffered from not having the underlying basis for being as “polite” and well behaved, or reliable, as we have come to expect from our electronics in the four decades since it was done.

As a result, the original was probably difficult to build in an assembly line fashion. Remaining samples have post-design manufacturing tweaks, and are still unreliable in operation. Furthermore, the original integrated console, with folding handle, articulated swivel-out footpanel and rocker must have been hideously expensive to manufacture. Then there is the huge collection of wires between the two major PCBs in the box.

Many of those things are still difficult to do well and at the same time economically today. So I took some liberties with the circuits for (1) easier building (2) better reliability and importantly, (3) adaptation to modern components for availability.

Lights: I ditched the small incandescent bulbs for LEDs. This kicked off a chain of things, but made for much easier construction. First, LEDs run from much lower voltages than the incandescents although about the same currents. To keep from burning out LEDs, you have to limit their current. I put resistors in series with them from the nominally 48Vdc power supply (see “Power Supply”), and found that I had to increase the resistor power rating to more than the 1/4W that I like to use. Instead of using bigger resistors, I took note of the fact that I could just series three 1/4W resistors to get a 3/4W rating. That’s why there are so doggone many 2.7K resistors in this thing. There are three on every LED, and ten LEDs. It is possible to use incandescent bulbs with these boards by finding grain-of-wheat bulbs and subbing them into the spaces for the LEDs, and jumpering or modifying the resistor values, and finding those little plastic color-covers. Me, I’d just use LEDs, but I’m lazy.

Power Supply: The original used an internal transformer to make 45-odd volts of DC from a center tapped arrangement. The PCB allows you to do that. The preferred way is to use a 48Vdc wall wart, which is available for under $20 at the time of this writing. Suitable transformers are hard to find, and bring in issues of AC power cord, fuse, and safe electrical wiring.

In my opinion, the 48V wall wart is so much better that I simply assumed that any builder would do it. If you have somehow convinced yourself that the original power transformer setup is audibly better, great! Go for it. Let me know how it works; but please, please be careful wiring AC wall power. I advise you not to do that, for both economic and safety reasons.

Modern Components: A part you can actually get and use has so much better performance than the perfect, original part that you can’t get that I specified all modern, easily available parts. (wink)

The original console switches are practically unavailable. Slide potentiometers are available, but they are an incredible pain for DIYers to use. So I used modern equivalents for all of them, changing the paddle switches to toggle switches.

I also wrestled with a nitty-gritty mechanical detail: how to mount all those switches, pots, LEDs and lights on a panel in a handy way. The switches would not have been a problem, except that one of the switches in the original has to be an On-Both-On action with at least two poles. These are available, but they are quite expensive (over $20 at the time of this writing). Worse, all the switches have to physically match for cosmetic reasons and for being able to mount them all the same way on the control/console PCB. For this to work, they all have to be the same height. There are six such switches, and if you pay $15-$20 for each one, it get out of the range for DIYers pretty quickly.

I thought about this for a while and finally figured out that the function done by that one pesky On-Both-On switch was the reverse of an On-Off-On switch that I could get if I thought of “On” as “Inhibit” and not actually “On”. With that realization, I looked at the circuit and saw that I could use two ordinary silicon NPNs on the PCB to convert the “on” from the original switch to “inhibit” and use the modern switches.

This not only let me use a $3 switch for the fancy function, it also let me get all the switch functions in a matching switch line so they could all have the same mounting height and mount on the PCB, as well as being the mounting for the PCB to the front panel. The M series from Mountain Switch does the job.

There may be other brands that do the same, but PCB mounting switches relies heavily on the exact pin size and spacing, so plan on using the specified brand and part number of switches. If you don’t, you’re accepting mounting the PCB an alternate way, and running about six to nine wires to each switch so they can be off the PCB, as well as a side effect of 2-3 wires per pot.

I looked for PCB mounted pots that had the same mounting height, and didn’t find any. What I did find was that standard (and cheap) 16mm panel mount pots were just a fraction of an inch shorter than the mounting height of the toggles, so I designed around the M switches. I specify 16mm panel mount pots without PCB pins. But the pots mount to the PCB with double sided foam tape on the back of the pot, which takes up the fraction of an inch of additional height. And the pot pins, which do not reach the PCB, can be extended into the PCB with cut-off resistor leads or short wires.

I tried to find stomp switches with a matching mounting height so I could get all of the wiring onto one controls-PCB. There were none I could find. I thought about making a third PCB with just the stomp switches on it, but realized that the same number of wires have to go between that PCB and the others as would be involved in just wiring the switches. No advantage.

One other circuit change involves making the animation LFO use a modern part. The LFO used a unijunction transistor (UJT), p/n 2N2646. These are still available, but they cost about $2.00 each. UJTs are one of those things which were good for what they did, but highly variable in operation. They were replaced by the modern programmable unijunction transistor (PUT), which does much the same thing, and only costs $0.25.

The 2N6027 PUT does a good job in this circuit. All it requires to use this part is some lead bending to get the leads in the holes originally intended to fit the 2N2646, and a couple of resistor value changes, as well as one additional resistor. I put a spot on the PCB to use that resistor if you want to use the PUT.

I also integrated a “feature” added to the original after they had all their PCBs printed. There is a terminal strip in the originals which holds an additional NPN transistor amplifier; I think this was used to bump up the signal level after the Ludwig was designed and found to have too little output level. I put that on the filter PCB as well.

There were a few miscellaneous resistor value changes that were made based on comparing the schematics pasted inside the units to the actual values used on the PCBs. Those are integrated into the clone PCBs and BOM too.

The originals had dismal reliability at least partially because they did not solder the nest of wires connecting the two PCBs and controls. Instead, they did a quick-and-dirty connection involving cutting a slot in the PCB edge and slipping a 0.25” quick connect terminal into the slot, the terminal being crimped to the connecting wire. I believe this was massively false economy. This scheme works great - for about a month, till the copper on the PCB that the connector touches starts to get dirty and corrode. This makes the warranty issues a commercial nightmare.

What’s an F board and a C board? There were two PCBs in the original; a “fall plate” and a “console”. This happens to fit nicely with a “filter PCB” and “controls PCB” which is how I use them. The part numbers with a F on them (e.g. “Rf7”) are on the filter board.

Bill of Material - page 1

Part Type	Designator	Footprint	Description
220pF	CF29	0.2” lead spacing, 0.1” wide	Mono ceramic, 0.2” sp
4.7n	CF10, CF11, C4, C5	0.2” lead spacing, 0.1” wide	Box Film, 0.2” sp
0.01u	C3, C7, CF16, CF18, CF25, CF27, CF3, CF33	0.2” lead spacing, 0.1” wide	Box Film, 0.2” sp
0.1u	CF4, CF5, CF7, CF8, CF28, CF2, CF19, CF9, CF+1	0.2” lead spacing, 0.1” wide	Box Film, 0.2” sp
0.15u	CF26, CF30	0.2” lead spacing, 0.1” wide	Box Film, 0.2” sp
0.22u	C13, CF12	0.2” lead spacing, 0.1” wide	Box Film, 0.2” sp
0.33u	CF17, CF20	0.2” lead spacing, 0.1” wide	Box Film, 0.2” sp
1u/50V	C2, C6	Radial 0.25” dia, 0.1” lead spacing	Cap-electro
2.2uF/50V	C1, CF14, CF32, CF23, CF22	Radial 0.25” dia, 0.1” lead spacing	Cap-electro
10uF 25V	C9, C10, CF1, CF6, CF13, CF15, CF21, CF24, CF31	Radial 0.25” dia, 0.1” lead spacing	Cap-electro
47u/63V	C8, C11, C12, C15, C16	Radial 8mm dia.	Cap-electro
3.9R	RF74[NOTE: not used on these boads]	0.5” lead spacing	Resistor 1/2w (not used)
100R	R22	0.4” lead spacing	Carbon film 1/4W
220R	R7	0.4” lead spacing	Carbon film 1/4W
330R	RF30	0.4” lead spacing	Carbon film 1/4W
470R	RF1, RF25	0.4” lead spacing	Carbon film 1/4W
1K	RF9, RF40, RF47, RF59, RF68	0.4” lead spacing	Carbon film 1/4W
1.8K	R26	0.4” lead spacing	Carbon film 1/4W
2.2K	R28, R29, R30	0.4” lead spacing	Carbon film 1/4W
2.7K	R33, R34, R35, R36, R37, R38, R41, R42, R43, R44, R45	0.4” lead spacing	Carbon film 1/4W
2.7K	R48 - 63,R65 - R70	0.4” lead spacing	Carbon film 1/4W
3.3K	R23, RF28,	0.4” lead spacing	Carbon film 1/4W
4.3K	RF37, RF58	0.4” lead spacing	Carbon film 1/4W
4.7K	R9, R10, R11, R25, R27, R31, R39, R40, R64	0.4” lead spacing	Carbon film 1/4W
4.7K	RF4, RF10, RF14, RF19, RF22, RF32, RF38, RF46, RF48	0.4” lead spacing	Carbon film 1/4W
4.7K	RF56, RF60, RF67, RF69, RF73	0.4” lead spacing	Carbon film 1/4W
6.8K	R14, R19, RF16	0.4” lead spacing	Carbon film 1/4W
8.2K	R17	0.4” lead spacing	Carbon film 1/4W
10K	R5, R6, R15, R75, RF+1, RF11, RF13, RF3, RF43, RF64	0.4” lead spacing	Carbon film 1/4W
12k	RF42, RF63	0.4” lead spacing	Carbon film 1/4W
15K	R21	0.4” lead spacing	Carbon film 1/4W
22K	RF5, RF20, RF21, RF34, RF39, RF44, RF51, RF52, RF61, RF72	0.4” lead spacing	Carbon film 1/4W
33K	RF2, RF76, Rtaper	0.4” lead spacing	Carbon film 1/4 W
47K	R1, R8, R12, R24, RF45, R46, R47,	0.4” lead spacing	Carbon film 1/4W
47K	RF+2, RF15, RF24, RF26, RF35, RF49, RF54	0.4” lead spacing	Carbon film 1/4W
47K	RF66, RF71	0.4” lead spacing	Carbon film 1/4W
68K	RF+3, RF36, RF57	0.4” lead spacing	Carbon film 1/4W
100K	RF12	0.4” lead spacing	Carbon film 1/4W
100K	R2, R13, R16	0.4” lead spacing	Carbon film 1/4W

Note: Part numbers containing an “F” are on the filter board. Parts with no additional letter after the designator (e.g. “R5”) are on the console/controls board. Parts with a “+” in them were added to the original. Parts with “alt” in them are alternate or optional. R17 is NOT the same as RF17. You have been warned.

Bill of Material - page 2

120K	R18	0.4” lead spacing	Carbon film 1/4W
150K	RF33, RF50, RF53, RF70	0.4” lead spacing	Carbon film 1/4W
470K	RF18, RF27, R32	0.4” lead spacing	Carbon film 1/4W
680K	RF7, RF8, RF23	0.4” lead spacing	Carbon film 1/4W
1M	R3, RF6, RF17	0.4” lead spacing	Carbon film 1/4W
10K	R20	BOURNS TRIMMERS	3306 or 3319 style
500K	R4	BOURNS TRIMMERS	3306 or 3319 style
25K	RF31	BOURNS TRIMMERS	3306 or 3319 style
25K	RF65	BOURNS TRIMMERS	3306 or 3319 style
50K	RF77	BOURNS TRIMMERS	3306 or 3319 style
50K	RF55	BOURNS TRIMMERS	3306 or 3319 style
150R*	RF29	BOURNS TRIMMERS	3306 or 3319 style (200R*)
500R	RF41	BOURNS TRIMMERS	3306 or 3319 style
500R	RF62	BOURNS TRIMMERS	3306 or 3319 style
Anim Rate	VR5	16mm Pane mount pot	B500K
BypassBal	VR2	16mm Pane mount pot	B10K
FFM Amp	VR6	16mm Pane mount pot	B10K
Fuzz Mix	VR4	16mm Pane mount pot	B10K
LowZBal	VR1	16mm Pane mount pot	B5K
Perc/Rpt	VR3	16mm Pane mount pot	B10K
Stereo FtSw	S8	DPDT stomp switch	
Anim Ftsw	S10	DPDT stomp switch	
Bypass Ftsw	S9	DPDT stomp switch	
Fuzz FtSw	S7	DPDT stomp switch	
DPDT Toggle	S1, S2, S3	TOGGLE 3PDT	1M31T1B1M2QE-EVX (Mountain Switch)
DPDT Toggle	S5, S6	TOGGLE DPDT	1MD1T1B1M2QE-EVX (Mountain Switch)
DPDT on-off-on	S4	TOGGLE DPDT	1MD3T1B1M2QE-EVX (Mountain Switch)
36V	D3	DIODE 0.4” lead spacing	Zener Diode, 36V 1/2W
1N4148	D1	DIODE 0.3” lead spacing	Diode
1N4148	D6	DIODE 0.3” lead spacing	Diode
1N4148	D2	DIODE 0.3” lead spacing	Diode
1N4004	D4	DIODE 0.4” lead spacing	Diode
1N4004	D5	DIODE 0.4” lead spacing	Diode
LED	LED1, 2, 3, 4, 6, 7,8, 9, 10	T1- ¾ LED	Pick your favorite colors
LED-R/G-CC	LED5	T1- ¾ LED	Bi-color LED, common cathode
NPN1	Q6: BD677/BD679/BD681/TIP112	TO-220	NPN darlington: BD677/79/81
NPN-EBC	QF+1, QF1-4,6-8,10,12-15,17,19-22; Q1, Q3-8; 2N5551 works well	TO92 EBC pinout	EIA Style, base in middle
PNP EBC	QF5, 9, 11, 16, 18; 2N5401 works well	TO92 EBC pinout	EIA Style, base in middle
2N2646	Q2; alternate is 2N6027, see text and schemo for mods to use.	TO-18	UJT; alternate 2N6027 see text

Misc: 4x mono phone jacks for inputs and outputs; stereo (T/R/S) jack for expression pedal; power jack to fit your selected power supply; hookup wire; solder; Some kind of rocker and treadle, like a sacrificial wah enclosure; chocolate chip cookies and foo-foo dust as required.

* Note that the original trimmer was 150R. Modern trimmers are either 100R or 200R, but the 150R value is almost unavailable. The best thing to do is to order the 200R value for RF29. Chances are, this will be fine, as the extra 50R just gives a bigger maximum range.

Note: Part numbers containing an “F” are on the filter board. Parts with no additional letter after the designator (e.g. “R5”) are on the console/controls board. Parts with a “+” in them were added to the original. Parts with “alt” in them are alternate or optional. R17 is NOT the same as RF17. You have been warned. Watch out for “Rtaper” !

Customization and Build Notes

In addition to the parts shown on the Bill of Materials, you'll also need a box, power input jack, three phone jacks for signal in and out, six knobs to fit the control potentiometers, wire, some kind of rocker/treadle mechanism, and other more generic supplies as well as a power supply. If you use a wah pedal, you will have to either replace the 100K pot with a ~~5K~~ 10K ~~or~~ construct the adapter shown later.

I recommend the following: Hammond 1590D enclosure; 48Vdc/0.125A wall adapter, Mouser P/N 709-GS06U-8P1J, $13.65. Think for a while what a 48Vdc power supply with a plug that also fits the DC power ports of your other pedals would do if you accidentally plugged the 48Vdc output into the pedals designed for 9Vdc. You may also want to buy a plug and a DC input jack that do not fit the Boss standard 2.1mm center pin DC jack like your other pedals. You have been warned.

Unless you (1) know what you're doing or(2) are a glutton for punishment or (3) both, buy the recommended set of switches.
3 each: 3PDT toggle, Mountain Switch/Mouser P/N 108-1M31T1B1M2QE-EVX
1 each: 2PDT ON-OFF-ON toggle, Mountain Switch/Mouser P/N 108-1MD3T1B1M2QE-EVX
2 each: 2PDT ON-ON toggle, Mountain Switch/Mouser P/N 108-1MD1T1B1M2QE-EVX

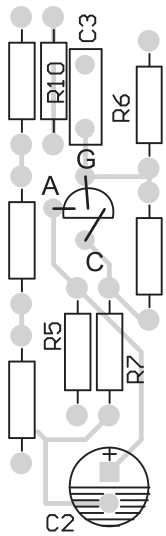
Not only do these switches do the necessary functions, the PCB was designed to fit them.

Be really sure to check the DPDTs for which one is the center-off before you mount them on the PCB, as they will look identical except for the part number, and the fact that the toggle stops in the middle of its travel. I personally hate to try pulling soldered-in switches off a PCB without damaging either the switch or the PCB. It's picky, time consuming work that sometimes fails.

Use your own favorite stomp switches, as they are connected by wires, not directly to the PCB. I think the wide-body Carling style will fit, although I have not checked it. The Carling 641 style is what I used as an example, and they will fit. You can use 3PDTs or even 4PDTs if you insist, but there is nothing for the additional poles to do.

If you decide to use the 2N6027 PUT instead of the 2N2646 UJT, the following changes need to be made.

- →Add Ralt1 = 4.7K or 5.1K on the PCB. Do not use Ralt1 with the 2N2646.
- →Install the 2N6027, with anode in the hole where the emitter of the 2646 went, cathode where the B2 terminal of the 2646 was, and gate where the B1 of the 2646 was, as illustrated in the sketch at right.
- →Change C2 to 2.2uF to restore the timing.

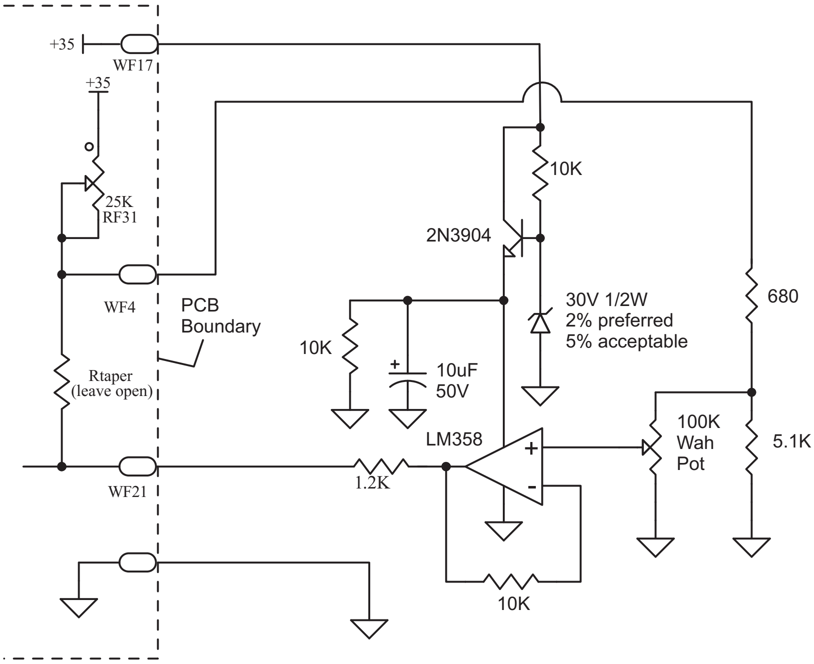


You can use other transistors. One unusual facet of the Ludwig Phase II is that it uses such a high power supply voltage. It uses 40+ volts at its input and then regulates that to about 35Vdc. This is very near the maximum voltage of the more common 2N3904/2N3906 devices used at lower voltages. I picked 2N5551/2N5401 devices, which are also plastic TO-92 devices, but which can withstand over 150Vdc. There is nothing special about the NPN and PNP transistors that has been found yet, and the 5551/5401 did work on the first test unit.

Q6 is under a lot of voltage and power stress. It was just one of the boys like all the other NPNs in the original, but I consider it marginal. I liked the higher power TIP112 device, and it did work well in the test unit.

Faking the ~~5K~~ 10K rocker pot with a stock wah pedal:

Yep, there is a way. You have to build a voltage buffer that can supply more current than the wiper of the 100K (typical) wah pot. A suitable circuit is shown below.

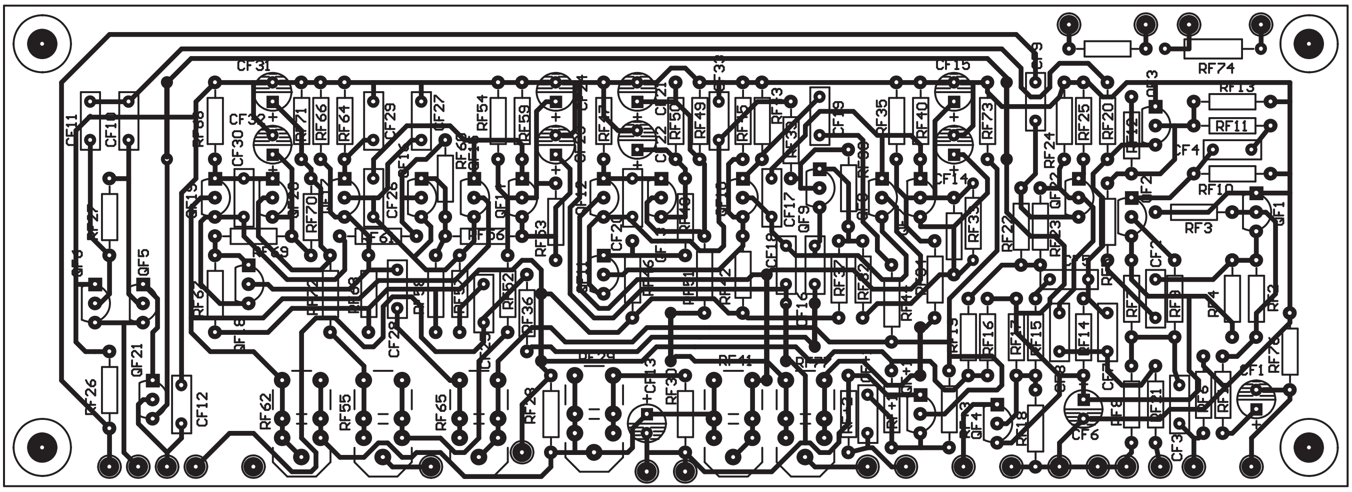


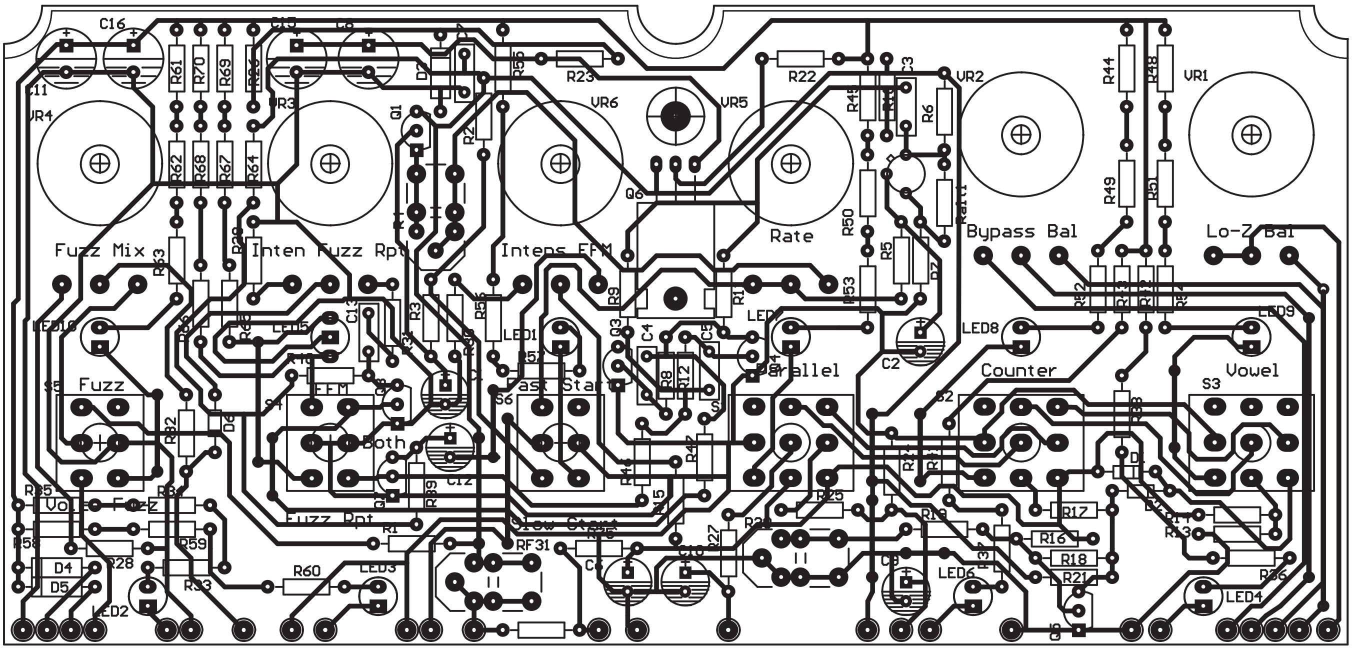
This would have been really easy if the power supply voltage on the Ludwig was not greater than 32V. As it is 35V or more, the voltage to the opamp has to be regulated down to 30V or so, and the input voltage to it has to be limited to less than that.

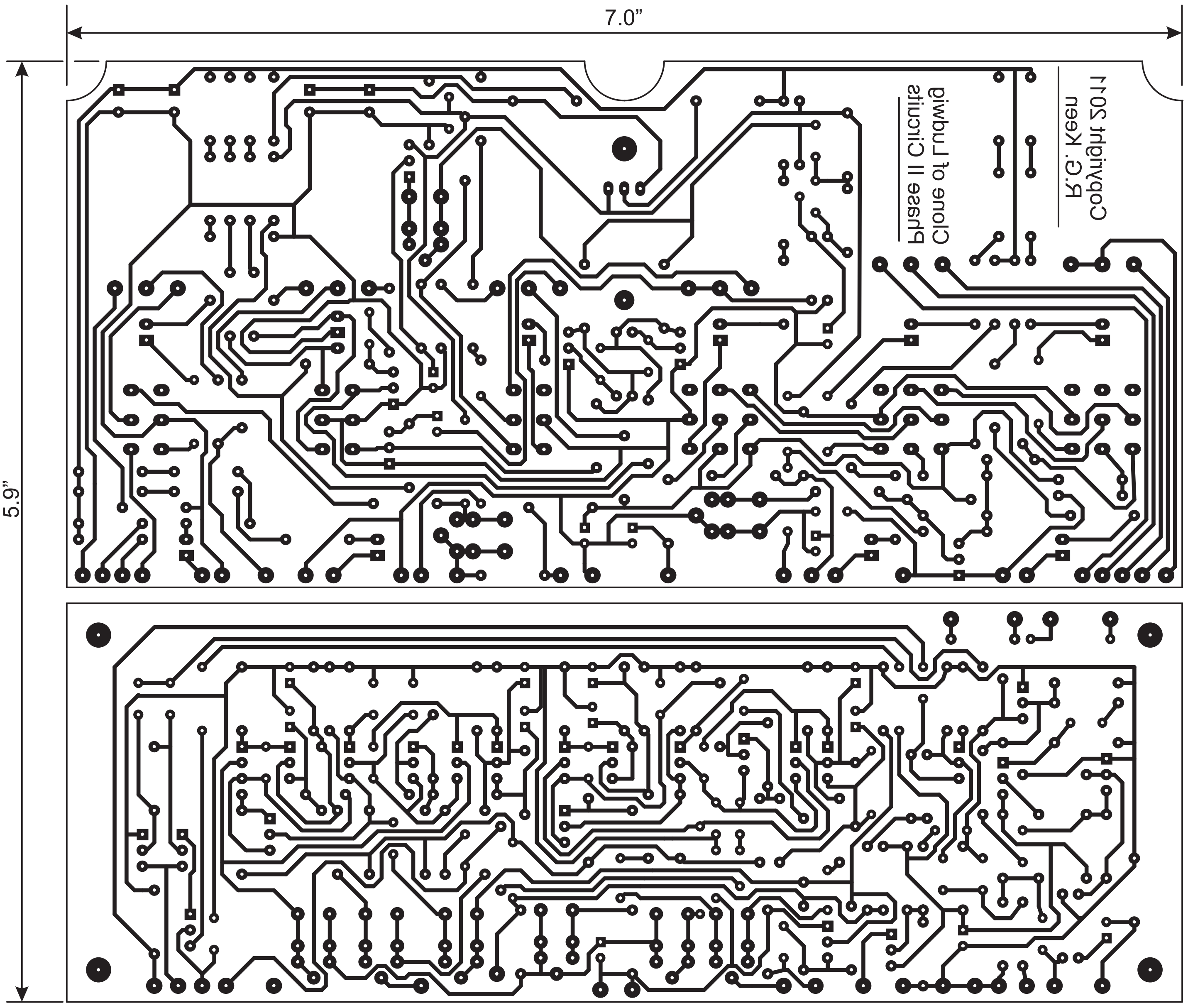
The general idea is that the wah pot generates a voltage on its wiper just like the ~~5K~~ 10K rocker used to do, and then the opamp supplies the current by following the wah pot voltage. The 1.2K resistor fakes the internal impedance of the ~~5K~~ 10K pot.

All the rest of that is to keep the opamp alive.

The +35 is taken from pad W17 on the filter board. The three other pads are where the ~~5K~~ 10K pot used to go. Rtaper is shown, but is not used in this circuit. You can experiment with tapering resistors on the 100K wah pot, but start with 680K - about the same ratio higher as the 100K is to the ~~5K~~ 10K. One half of the dual LM358 is not used. You can tie its output to its negative input, and its positive input to the wah pot wiper. This makes sure it is not oscillating, although its output goes nowhere.




Fuzz Mix
Inten Fuzz Rpt
Intens FFM
Rate
Bypass Bal
Lo-Z Bal
Fuzz
FFM
Fast Start
Parallel
Counter
Vowel
Both
Fuzz Rpt
Slow Start


7.0”
5.9”
Phase II Circuits
Clone of Ludwig
R.G. Keen
Copyright 2011

ARGH! It doesn’t work!!

OK, you got it all populated with parts, spent your several hours wiring it up and, then you decided to just give it a go on the theory that it may just work first time.

That gets you three points for initiative and confidence, but loses you seven points for not checking it out first.

Sorry - this thing has a lot of parts and some complex wiring. Don’t expect it to just work. It is possible that could happen, but don’t place any large bets on it. Expect to check it out first, and do some tuning. The fully-functional original units we used for comparison didn’t sound right until they were (laboriously!) tuned and trimmed up.

Divide this chore up into two main parts: voltage checks before tuning to make sure everything has a chance to work, then a process of actually tweaking it in to make the neato sounds it can make. The first voltage checks are to filter out the bad solder joints, wrong/backward parts placement, and other forehead-slappers that creep into every hand-made audio board. Be patient, and be gentle with yourself.

Voltage checks:

Check out your external power supply with a voltmeter before plugging it into the boards. Be sure it gives you the voltage (over 35Vdc) and polarity on the plug that you expect.

Plug it into your boards, then check the DC voltages on the PCBs to be sure your wiring is getting the DC to the right places on the PCBs. The following voltage check table is a guide, not hard and fast rules. If you voltages are similar, it’s probably OK. If they’re wildly off, you may have problems.

	E	B	C	Test Condition, notes.
QF+1	0	0.6-0.7		
QF1	0	0.6-0.7	3.0	
QF2	3.7	4.2	10.3	
QF3	0	0.6-0.7	7.7	
QF4	2.8	3.1	10.3	
QF5	3.3	2.6	0.2	
QF6	0	0.6-0.7	0.2	
QF7	3.6	4.2	8.8	
QF8	3.6	4.2	8.8	
QF9	19.8	19.2	11.2	
QF10	10.6	11.2	18.7	
QF11	19.4	18.7	15.8	
QF12	3.6	4.2	15.8	
QF13	3.6	4.2	14.9	
QF14	3.6	4.2	17.4	
QF15	3.6	4.2	11.4	
QF16	19.6	18.9	11.4	
QF17	10.8	11.4	18.9	
QF18	19.5	18.9	15.6	
QF19	3.6	4.2	15.6	
QF20	3.6	4.2	17.6	
QF21	3.3	3.83	10.2	
QF22				
Q1	31.6	29*	34-36	* base appx 0 with rate switch on "slow"
Q2				UJT, too hard to read with voltmeter
Q3	0	0/~0.6	~0/~13.5	Animation footswitch on; voltages switch between values
Q4	0	0/~0.6	~0/~13.5	Animation footswitch on; voltages switch between values
Q5	0	0.6-0.7*	8.05*	Base 0.6-0.7 with animation on; C 8.1 with animation off, jumps between 6 and 10V with animation on
Q6	33.5-36.0	34.1-36.6	Over 38	Collector is within 0.7V of input voltage
Q7	0	0/~0.6	~0/~13.5	Animation footswitch on; voltages switch between values
Q8	0	0/~0.6	~0/~13.5	Animation footswitch on; voltages switch between values

Appendix 1: Errata on R.G.'s Second Attempt

The first set of commercially made boards contained the usual bugs that a first PCB layout has. Thanks to the people who were brave enough to dive into these boards, we have a list of corrections that fix these. Special thanks to Andy M., who *financed* a commercial batch of PCBs for the group, and Dino, who took on the herding-cats job of parceling them out to people who wanted them.

0. BOM bugs have been corrected in this document as discovered.

1. Hole sizes: The holes for the leads on the 1N4004 diodes and Q6 are a little small. Some manufacturer's parts may not fit through them; some will, but it's tight. It's OK to drill out the insides of these holes a little, being careful not to take away too much of the pads.

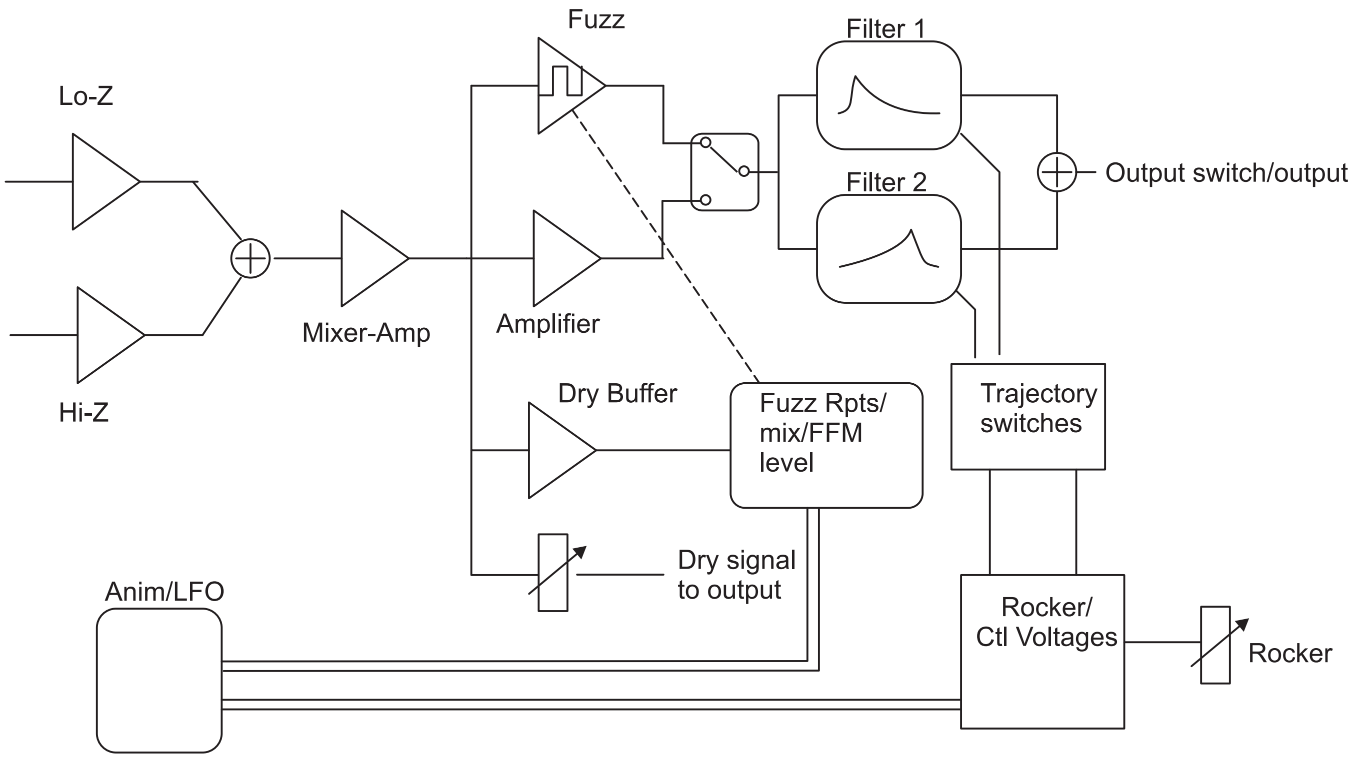
2. C12 is shown on the PCB as a 6mm diameter package. It is rated at 47uF (50uF)/63V. There are 47uF/63V capacitors available in 6.3mm diameter by 11mm tall radial packages. It is also OK to relax the voltage specification on this cap to 47uF/50V. There are more choices available in the lower voltage to get the package smaller than 6.3mm diameter and 11mm tall. If you can't find one of these, you can put a larger package C12 on the bottom/copper side of the PCB.

3. The rocker pot was discovered to be 10K, not 5K, in the original units. This document has been updated to that effect as of 4/1/2012.

Appendix 2: The Technology Of...

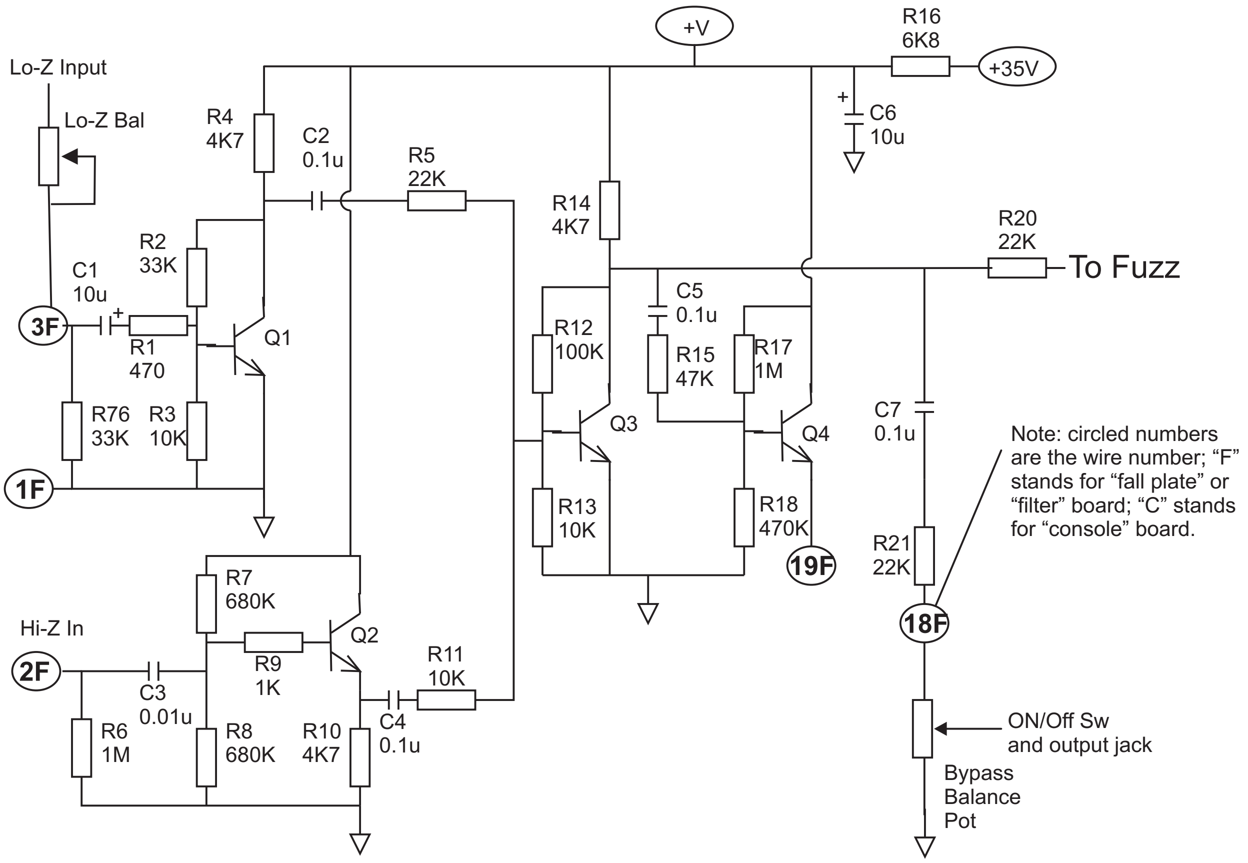
I spent some time puzzling out how this thing works in terms of what whole sections do what functions, and some of how they work.

Here's an overall block diagram.



Block Diagram

Inputs, mixer, and buffers



The Ludwig Phase II (Ludwig) has two inputs, a low impedance (Lo-Z) and a high impedance (Hi-Z). The two are intended for different sources. The Lo-Z would likely load guitar down too much by modern standards, causing treble loss. The Hi-Z is more likely to be used for guitar today.

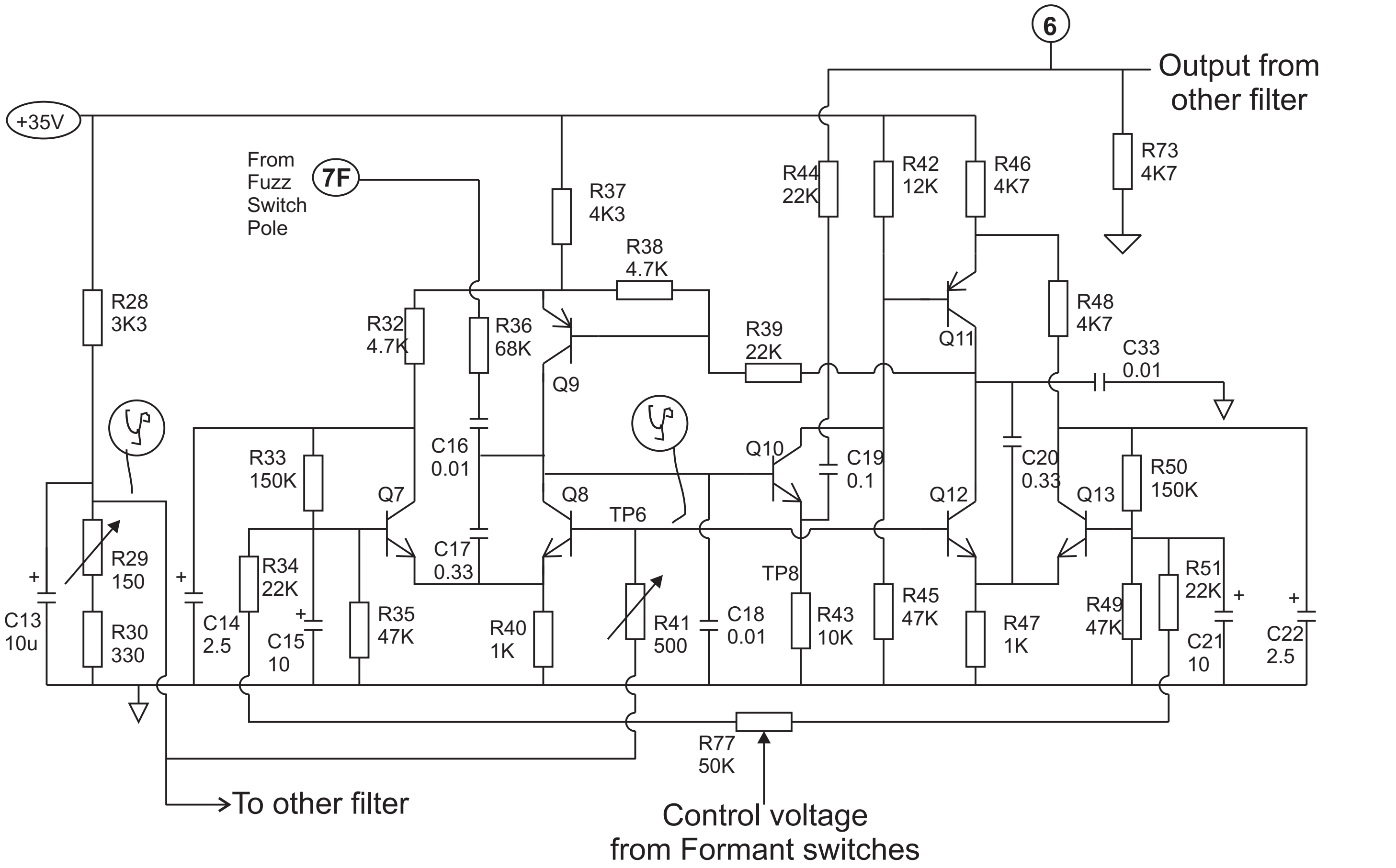
Oddly, the Hi-Z input has no gain. A mod to insert a resistor into the Q2 collector circuit and take its output from the collector instead of the emitter would likely give more signal level to a guitar. It’s a good place to start for tinkering.

The Lo-Z and Hi-Z signals are mixed by R5 and R11 into Q3, where they are amplified and sent to both fuzz and a follower output. The follower output is the emitter of Q4, on pin 19F (wire number 19 on the filter/fall plate circuit section). R20 limits current from Q3 collector into the fuzz circuit input.

The output of Q3 is also the signal sent to the output jack when the effect is not engaged. It goes to the bypass balance pot and then to the “effect on/off” switch and the output jack. The Ludwig is a buffered-bypass pedal in the sense that there is no bypassing, only an unaffected signal when the effect is not engaged.

Q4 buffers the output of Q3 and sets a DC level of about 1/3 of the power supply for signal to the Fuzz Mix section; this output appears at pin 19F.

Filter and Trimmers



There are two filters, identical except for minor differences in frequency range. One is shown. They take in the signal from the fuzz select switch, either amplified normal signal or fuzz signal, and then output to R73, which mixes the two outputs. The filters are bandpass filters, and their frequency range corresponds to the first and second formant frequencies of the human voice. Each filter by itself sounds much like a wah pedal, but with different frequency ranges.

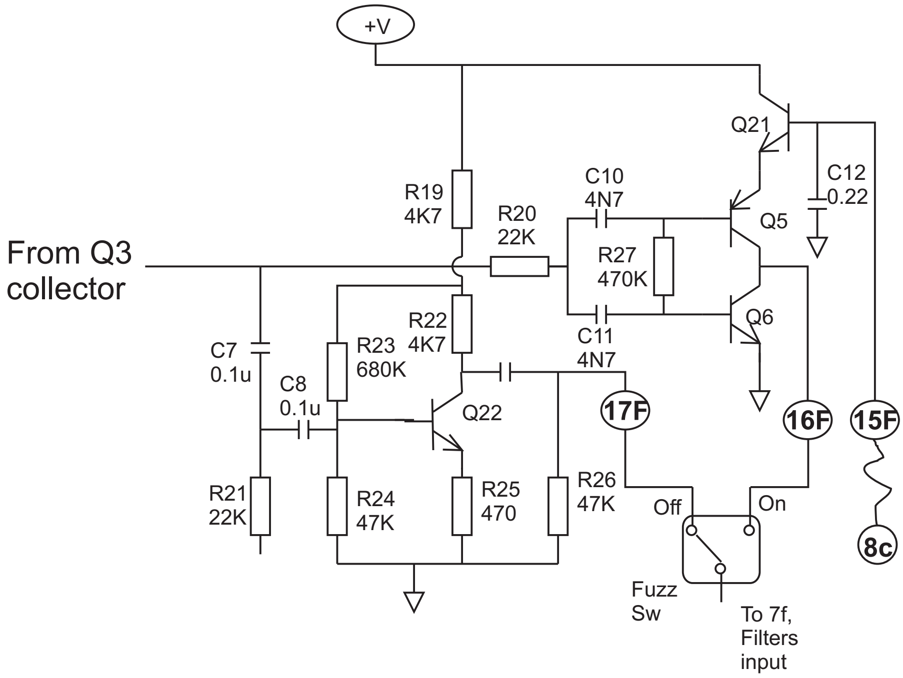
It is not clear to me exactly how the filter itself works in detail. But they do work, both in breadboards and in simulation.

Each filter's center frequency is controlled by a control voltage fed to it through the formant switches and into the wiper of a trimmer that sets some kind of balance between the two halves of each filter. For the filter shown, this is R77, for the other one it is R55. Both filters are fed a control voltage created by R28-R29-R30. This control voltage is critical in setting the filters up, as they only work in a narrow range of about 1.8-2.2V of this control voltage. R41 and its counterpart R62 in the other filter set some kind of internal sensitivity to the master control voltage. Someday I'll figure out more about this.

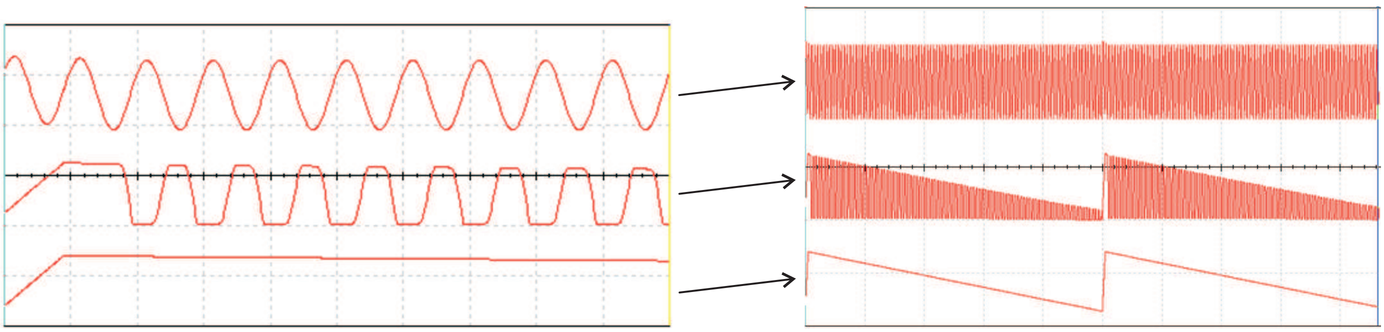
The fundamental action of the Ludwig is to set up control voltages to these two filters, sweeping both center frequencies in "trajectories" selected by the formant trajector switches, so that they do one of (1) sweeping up and down in frequency together, (2) one sweeping up while the other sweeps down, and (3) a "vocal" sweep, with the center frequencies moving in some approximation of what the F1 and F2 formants of human voice do in speech. If this last is set up well, a sweep of two or more distinctly vowel sounds results.

Exactly how the voltages are swept is controlled selectively by the rocker pedal and an "animation" feature which repeatedly creates a slow speed sweep.

Fuzz/non-fuzz signal to filters

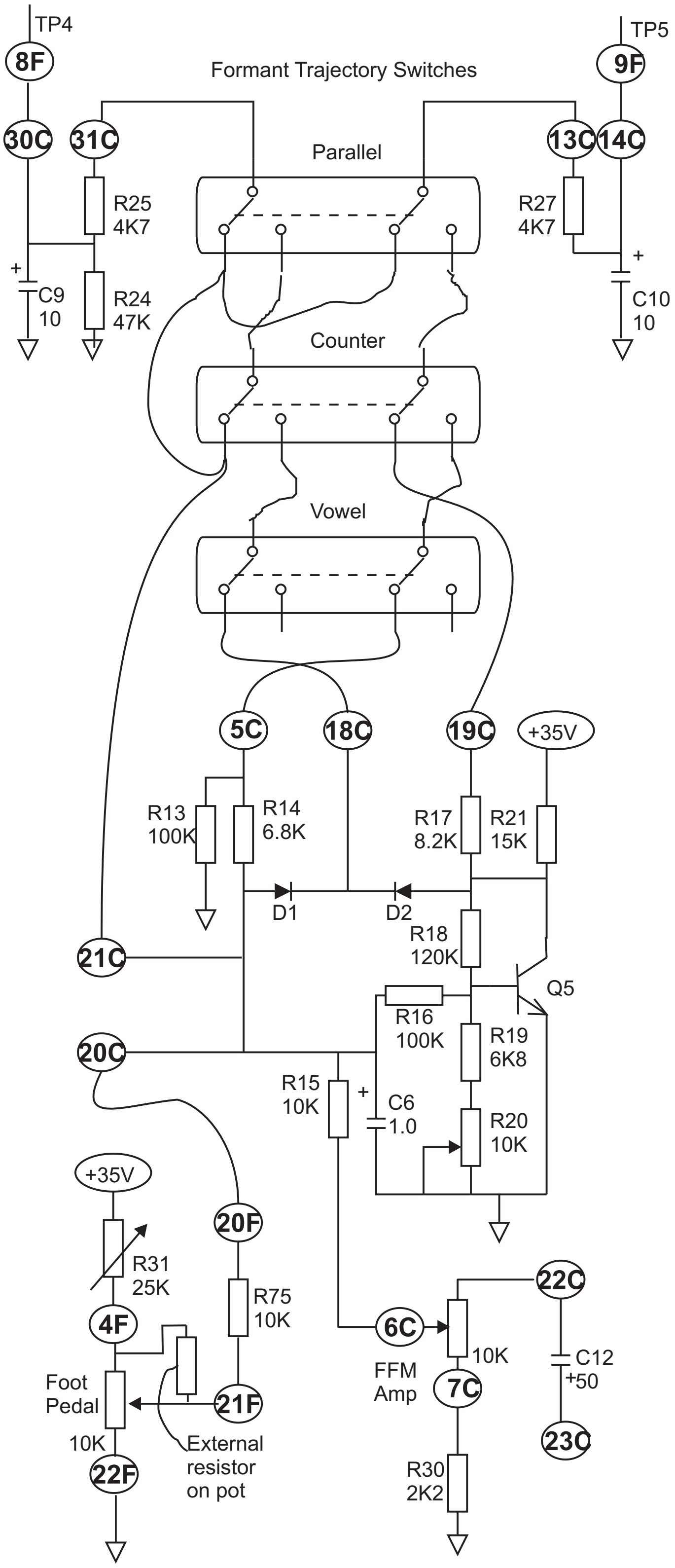


The fuzz/non-fuzz section provides the signal to the filters. Non-fuzz just amplifies up the normal signal. The fuzz circuit Q5-Q6 amplifies the normal signal up to a square wave. The size of the square wave is determined by the voltage on Q21 emitter. This is in turn set by the signal on pin 15F. This comes from the fuzz repeats section of the unit, and causes the fuzz signal to be amplitude modulated. A signal from about 1.8V to 7V here raises the fuzz output signal on pin 16F from zero through about 7V, the peak voltage following the level of Q21 emitter. This is used for a percussive repeat effect. Pin 17F is the non-fuzz signal amplified up to a consistent level. The fuzz switch selects which signal is submitted to the filters.



The signal at pins 8C/15F 8 is from the fuzz animation circuit. It is a slowly swept DC level, and causes the fuzz level to increase as it increases. The pictures are captured traces from simulating the circuit. The top trace is a sine wave input signal; the bottom trace is the modulating signal at 15F, and the middle trace is the resulting output at 16F.

Formant Trajectory



The formant frequency control voltages at 8F and 9F come from the formant trajectory switches. These are scaled to size by R25, R24, and R27, and smoothed by C9 and C10. The trajectory switches pick whether both filters get the same control voltage (parallel) or opposite (counter) going voltages, or the special vowel combination.

The control voltages are generated by the action of Q5, which is set up as an amplifying inverter. A varying DC voltage is fed to Q5 base through R15 and R75. The voltage at pin 19C rises when the input voltage falls, and vice versa. The voltage at pin 5C rises and falls with the input, and the voltage at pin 18C rises with the higher of either the input voltage or the collector voltage of Q5; so it starts high, falls, then rises again whether the input voltage rises from minimum or decreases from maximum. This reversal in direction corresponds somewhat to the frequencies of the human vocal formants, and is responsible for the vowel sounds the Ludwig can do.

If the “parallel” switch is set, the filters both rise and fall with the input voltage to the Q5 circuit.

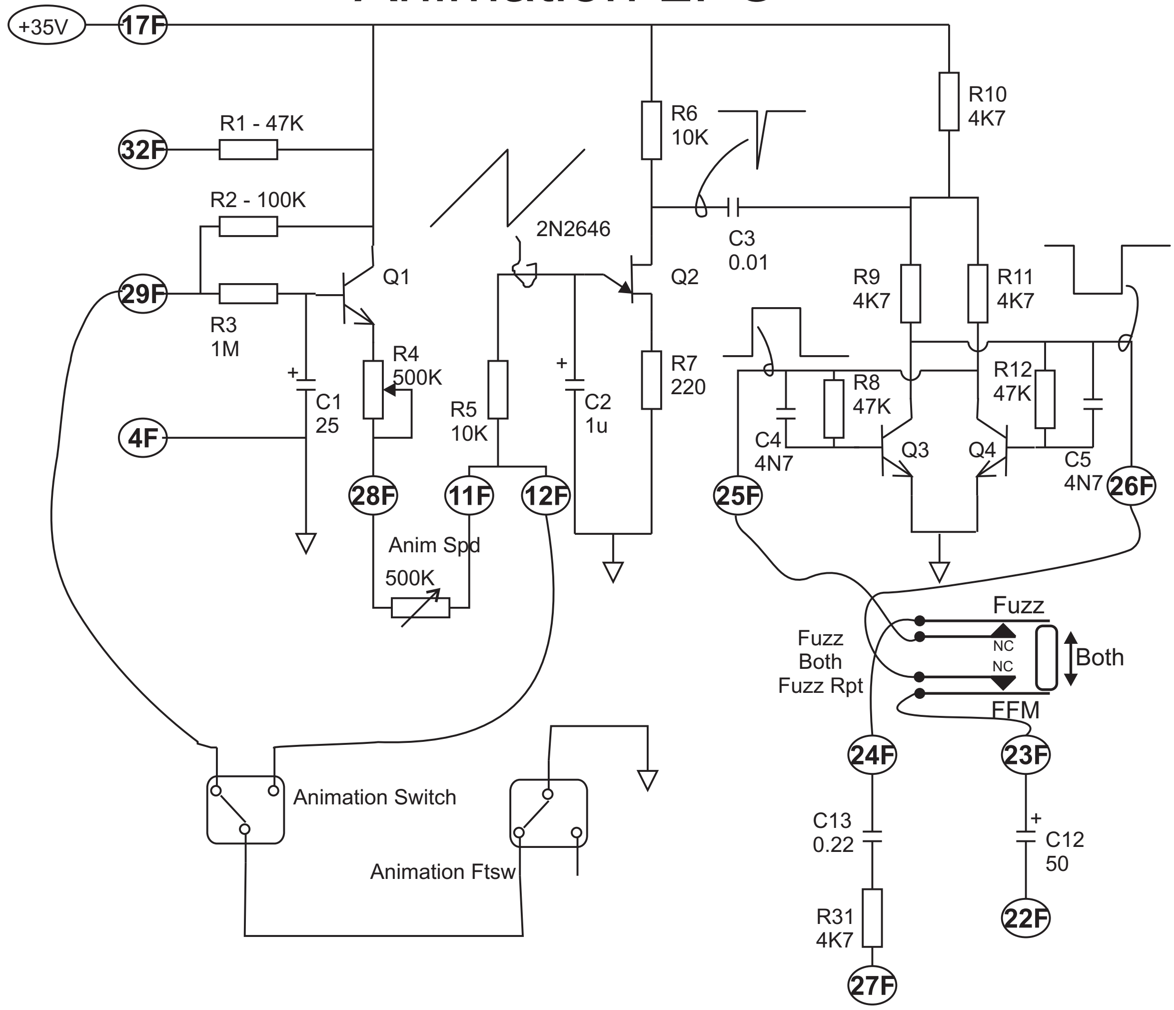
If the parallel switch is off, the control voltages can come through the “counter” switch. The counter switch selects either the opposite-going voltages from the input voltage at pin 21C and pin 19C, or the output of the “vowel” switch. The opposite-going voltages make the filter frequencies move in opposite directions in frequency.

If the vowel switch is on, the control voltages come from pins 5C and 18C. This allows the emulation of vowels in the filters. To hear vowel simulation, “parallel” must be off, “counter” must be off, and “vowel”must be on. Counter pre-empts vowel, and parallel pre-empts counter.

R20 sets the bias on Q5 to get good inversion range and DC bias for Q5.

The input to Q5 is the sum through R15 and R75 of the rocker pedal voltage and the voltage from the animation oscillator through C12. R31 sets the maximum voltage across the rocker pedal, and hence the voltage range from the rocker pot. The rocker pot has a “tapering resistor” soldered across its lugs as shown. The FFM control pot selects a portion of the signal from the animation LFO output at pin 23C through C12. The signal from the animation LFO is a low frequency square wave; C12 prevents this from changing the DC bias of Q5, but allows through a repetitive low frequency changing voltage. This wobbles the input voltage around the DC position set up by R20 trimmer and the foot pedal rocker.

Animation LFO



The Animation section creates a pair of opposite-phase square waves at pins 25C and 26C. These signals come from the collectors of Q4 and Q3 respectively, which are set up as a digital flip-flop. One collector is always high, and the other is always low. High is about 16V and low is nearly zero. The fuzz/FFM repeats switch selects whether you get animation on the frequencies in the filters, fuzz repeats or both. Both outputs are AC coupled to prevent the square waves from the flipflop from affecting the DC conditions on the circuits they feed, but the capacitors (C13 and C12) are large enough to couple the resulting AC signals into the corresponding circuits.

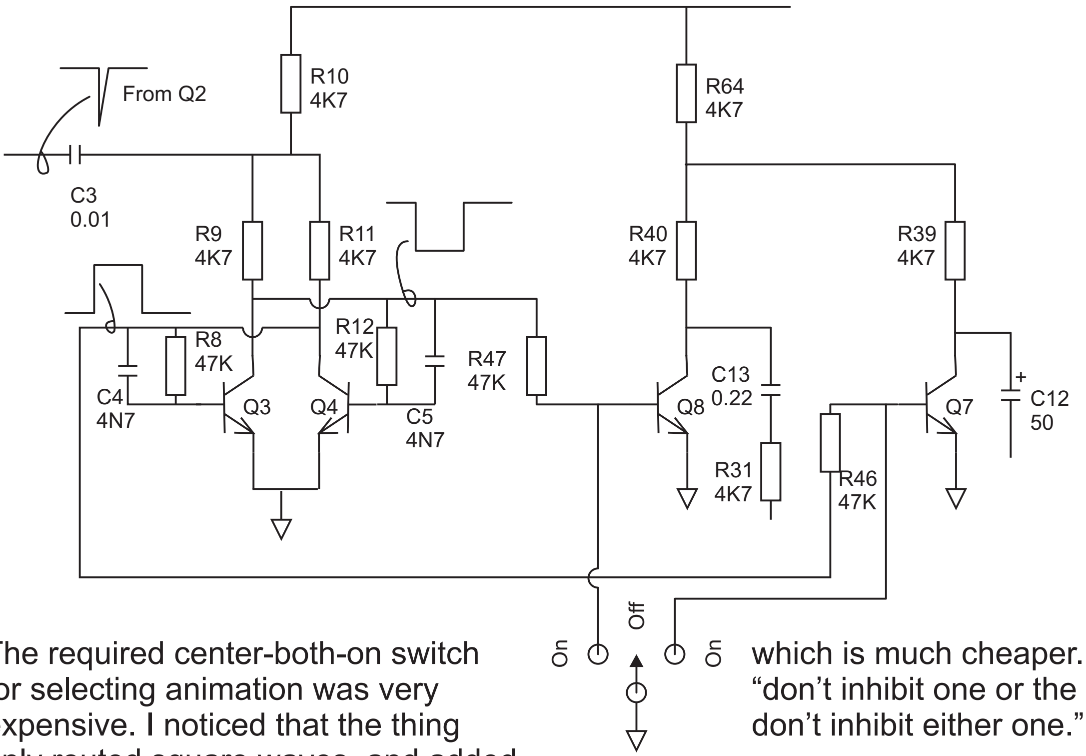
The flipflop inverts at a rate determined by negative-going pulses through C3. The value of C3 may need to be adjusted so that the size and sharpness of the pulse from Q2 causes reliable triggering. 0.01uF, 0.1uF, or 1uF may be used/needed.

Q2 is a standard unijunction transistor (UJT) oscillator. This produces large negative pulses at B2 (connection of R6 and C3, and smaller positive pulses at B1 (top of R7). The timing is set by the voltage on C2. At power-on, the voltage at C2 rises from zero. When it reaches a critical voltage set by the nature of Q2, Q2 suddenly conducts from the terminal connected to C2 very heavily, and continues to conduct until C2 is almost drained. Q2 then turns off, and C2 begins charging again. The sudden conduction is what causes the negative-going pulse on C3, and also the change in state of the flipflop.

C2 voltage rises at a rate determined by the voltage fed to it through a series resistance. In this case, the resistance is the sum of R4, R5, and the animation speed pot. Larger resistance makes C2 charge more slowly, so the time between flipflop inversions is longer. Smaller resistance makes this faster. Changing the animation speed pot changes the resistance, as does trimmer R4, which sets how small the total resistance can be, and hence how fast the animation can get. At some low setting of total resistance, Q2 will lock up and not oscillate. The setting of R4 can prevent this; it's probably why it's there.

The voltage fed to the series timing resistance comes from the emitter of Q1. Q1 is an emitter follower, fed a DC voltage through R2+R3. If the animation switch and animation footswitch are open, this is connected to the power supply voltage, and Q5's emitter sits at nearly 35V. If the animation switches ground pin 29C, then the base is pulled to ground and oscillation of Q2 stops, as does the output changes of the flipflop. C1 and R set how fast the voltage Q1 emitter can change, and therefore how fast the animation turns on and off. This can produce a ramping up/down of animation speed.

Animation LFO in the Clone



The required center-both-on switch for selecting animation was very expensive. I noticed that the thing only routed square waves, and added two "echo" transistors to make similar square waves, but which could be inhibited by grounding their bases. This let me use a center-off switch which is much cheaper. The logic function is "don't inhibit one or the other, and center don't inhibit either one."

Percussion Repeats

At right is the fuzz repeats/animation circuit. The level of output from the fuzz circuit depends on the voltage on the base of Q21, from pin 15F. In one position of the fuzz switch, the buffered signal from Q4F at a DC level of about half the 35V power supply is connected to the fuzz mix control. In the other position, a fixed 47K to +35V is connected. This lets the fuzz mix control vary between about half the power supply and nearly ground in the Q4F position, and about 8-9V in the R1 position. This DC level sets the DC for the base of Q21, and hence the fuzz level.

The LFO can be added into this through the percussion repeats pot, which lets in a portion of the square wave LFO output, and makes the fuzz jump up and down in level as the LFO cycles. The amount of jump is controlled by the setting of the percussion repeat pot. The diode prevents the LFO from actively pulling down on the level, so it jumps up and decays back down, like a percussive signal.